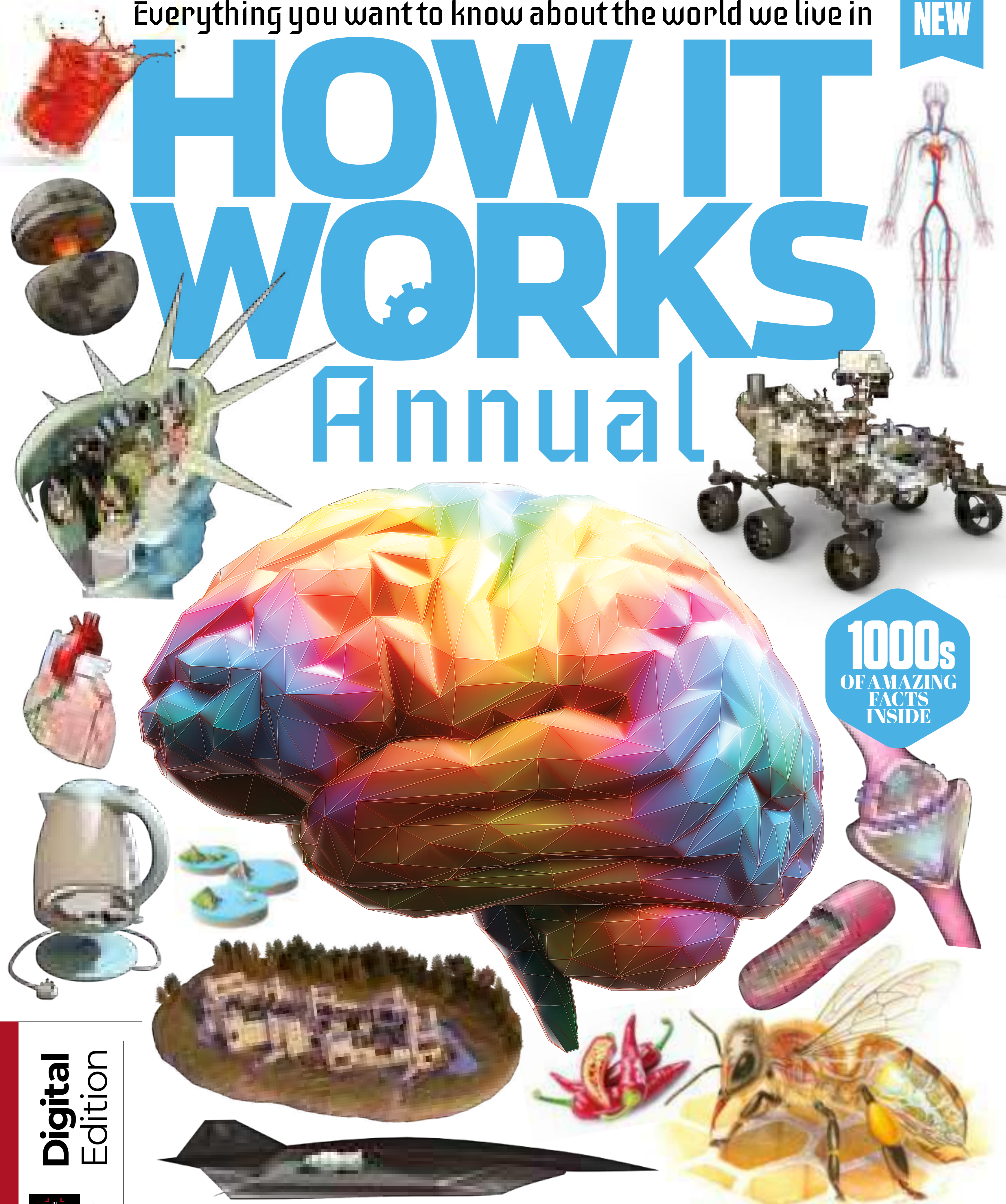
Everything you want to know about the world we live in

NEW

HOW IT WORKS Annual



1000s OF AMAZING FACTS INSIDE

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FUTURE

VOLUME 13

SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

WELCOME TO

HOW IT WORKS Annual

Welcome to the How It Works Annual volume 13, a carefully curated compilation of our favourite new How It Works features. As ever, they're packed with eye-catching illustrations, expert interviews, and filled with mind-blowing facts.

We've cherry-picked the topics we think you will love from across our six categories - science, environment, technology, history, space, and transport. Discover 10 weird things about your brain and the strange ways your mind works, what would happen if the the Earth was a flat disc rather than a sphere, explore the scientific reasons behind UFO sightings and discover objects we've spotted in the sky that we genuinely have no explanation for, then delve into the incredible, tiny worlds of both nanotechnology and quantum computing. Also: what makes chillis spicy, inside an Atari 2600 video games console, how the Statue of Liberty was built, how an electric kettle works, and loads more. It's feast of fascinating and fact-packed features - enjoy!

FUTURE

HOW IT WORKS Annual

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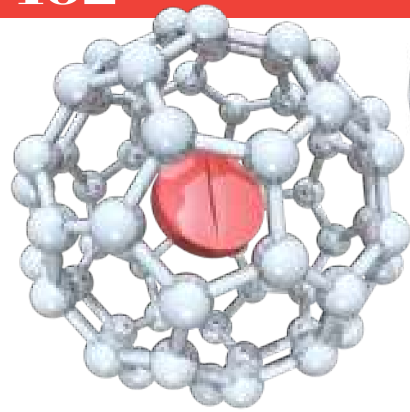

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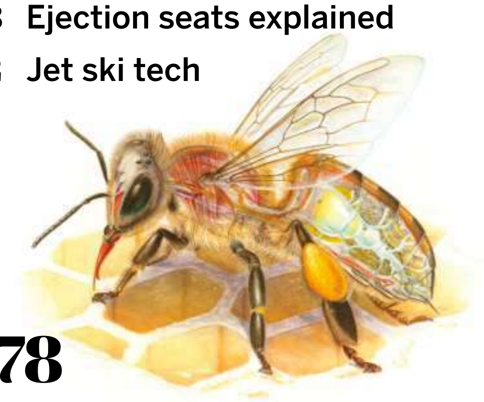

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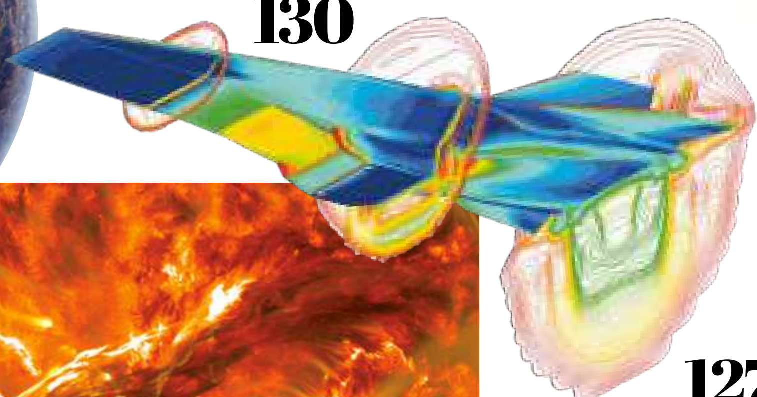

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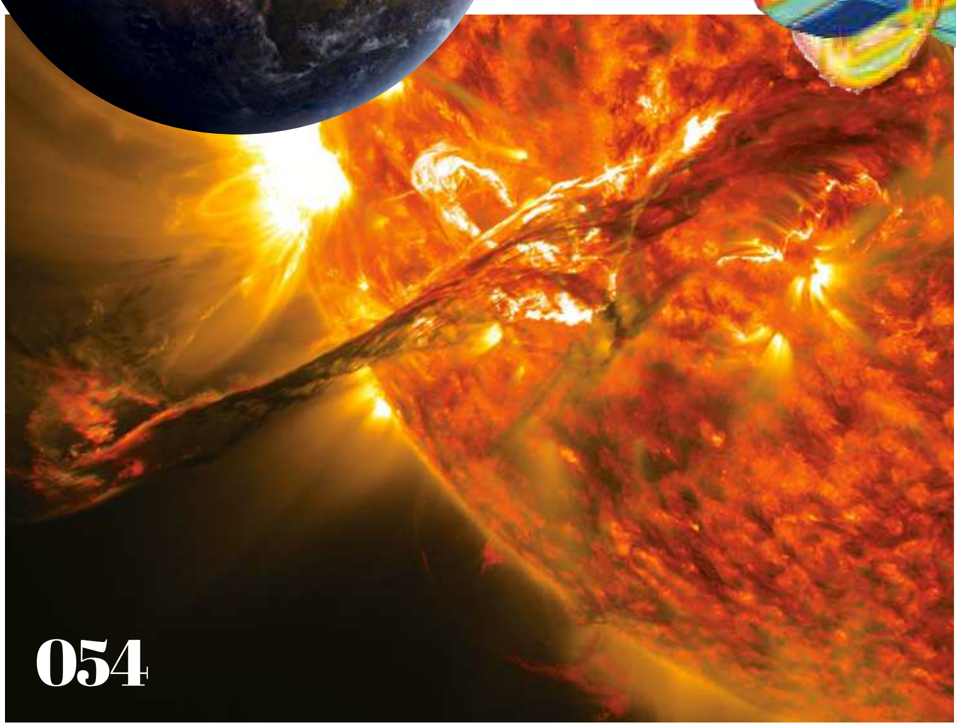

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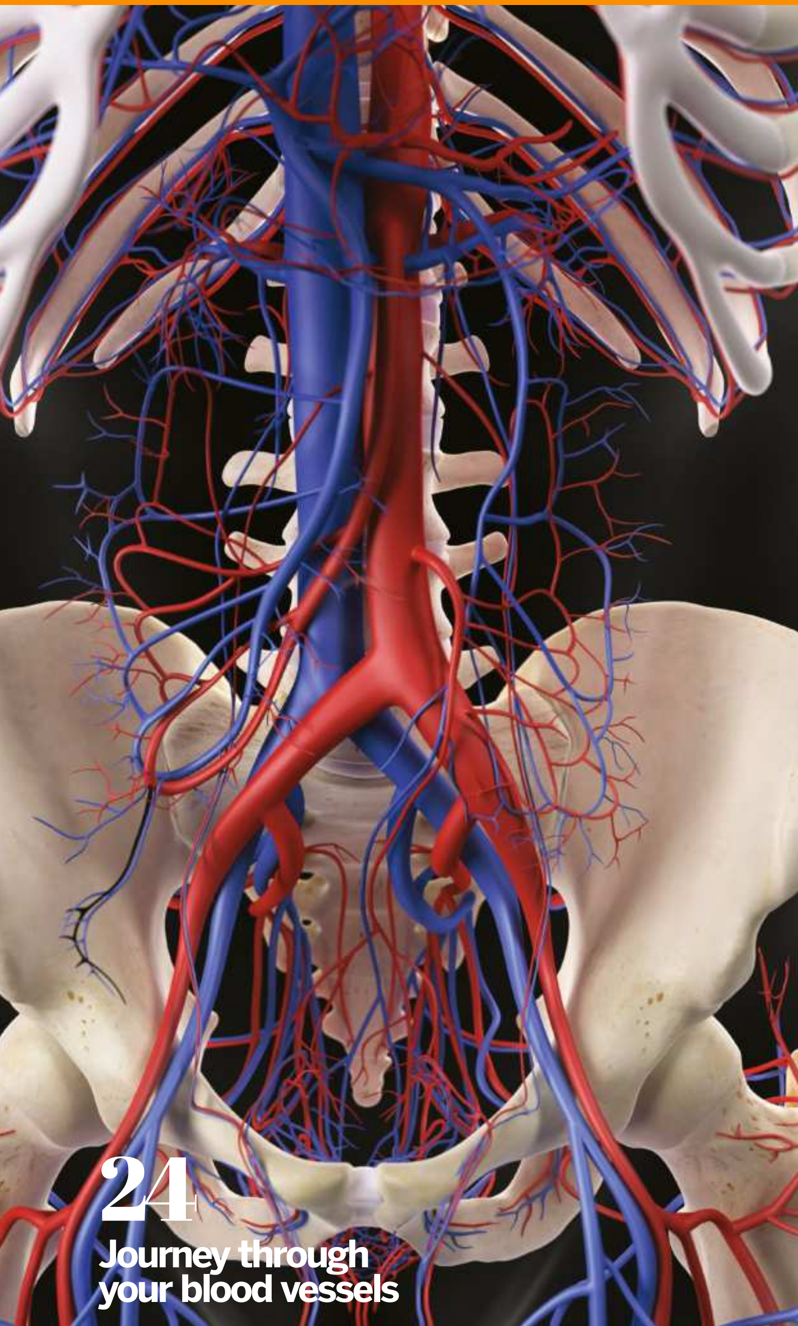

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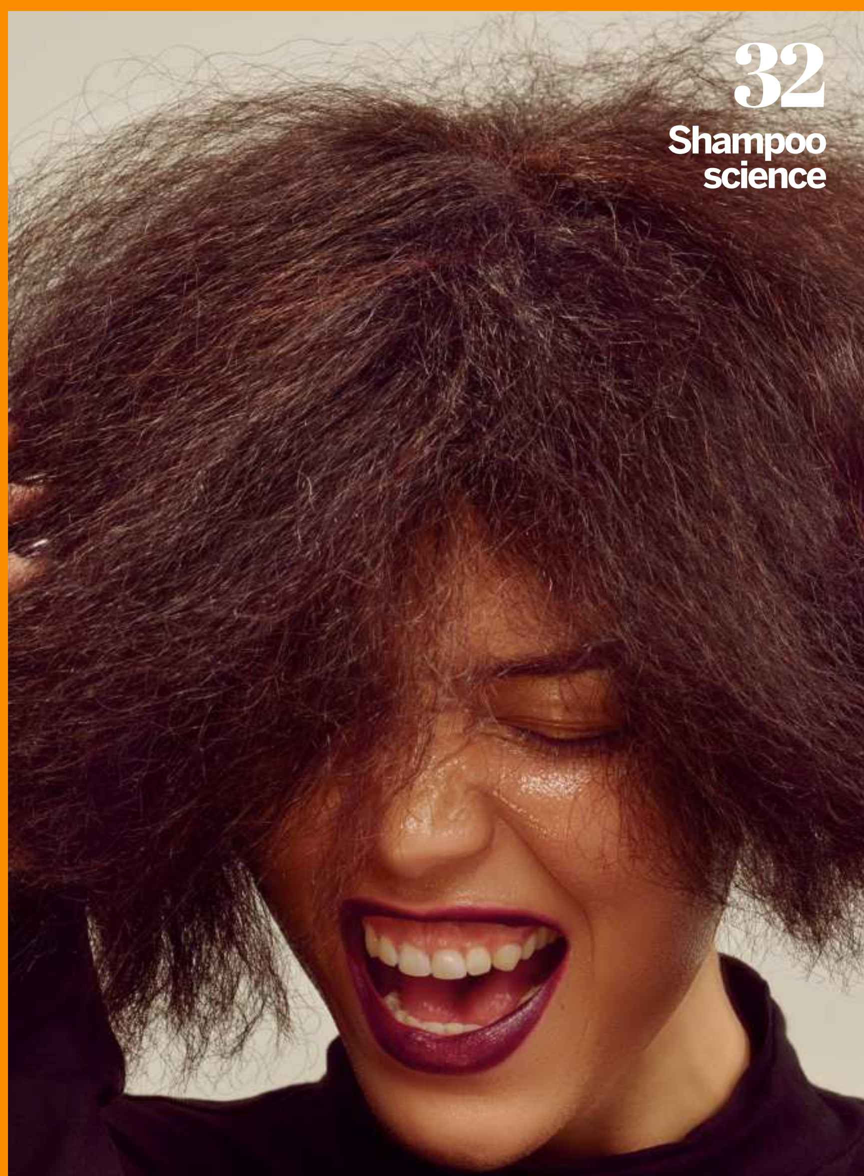

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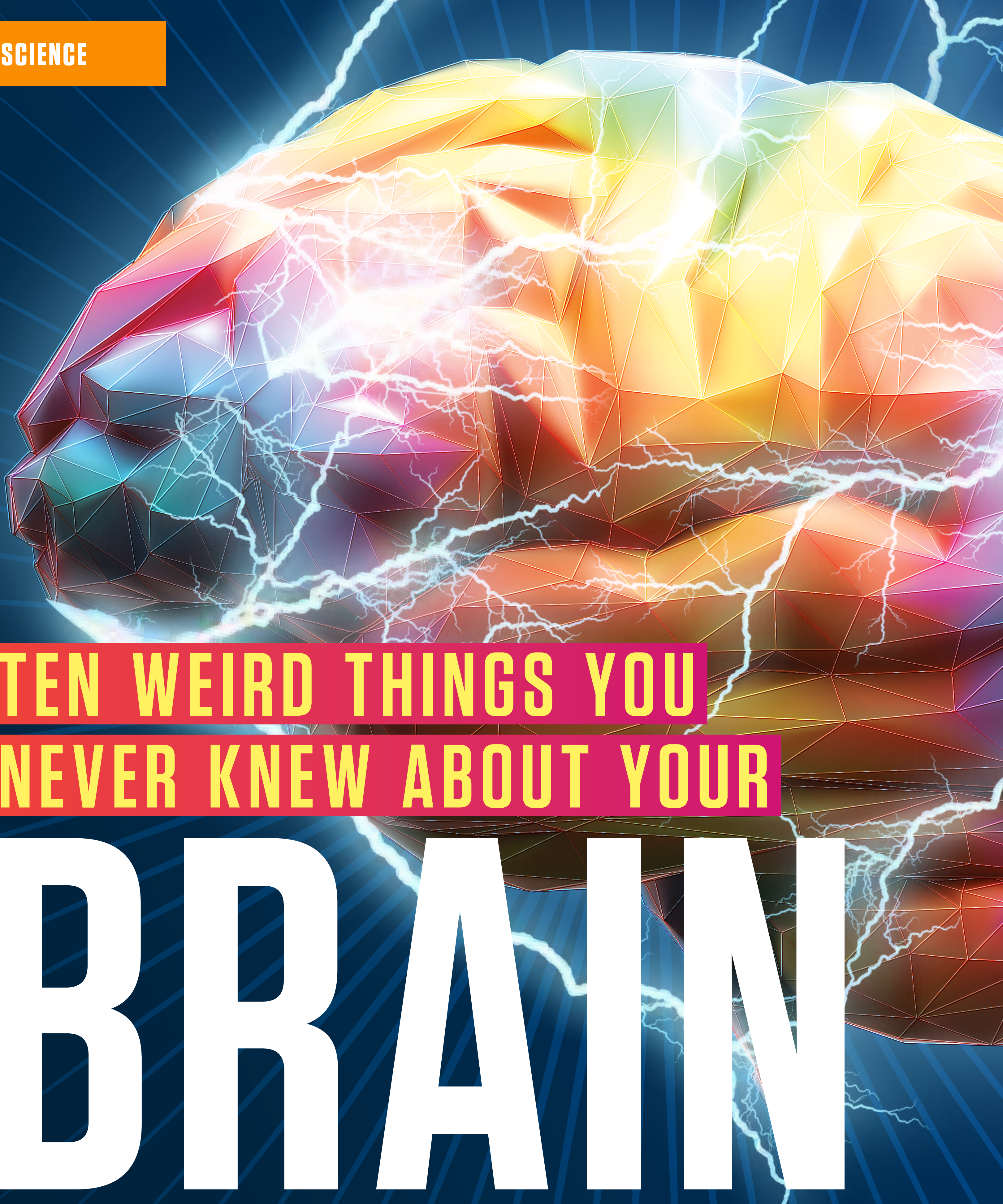
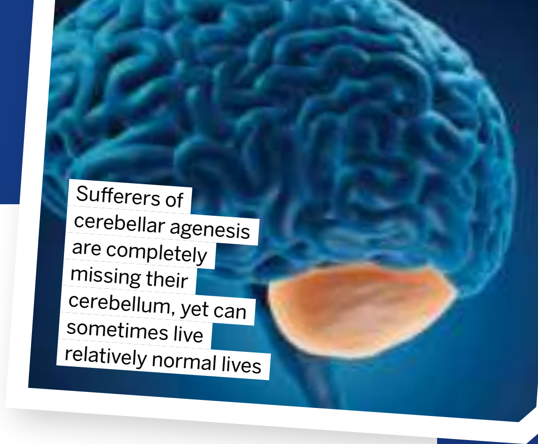


TEN WEIRD THINGS YOU NEVER KNEW ABOUT YOUR BRAIN

Discover the science and psychology behind the brain's fascinatingly quirky and unique design

WORDS JAMES HORTON



Sufferers of cerebellar agenesis are completely missing their cerebellum, yet can sometimes live relatively normal lives

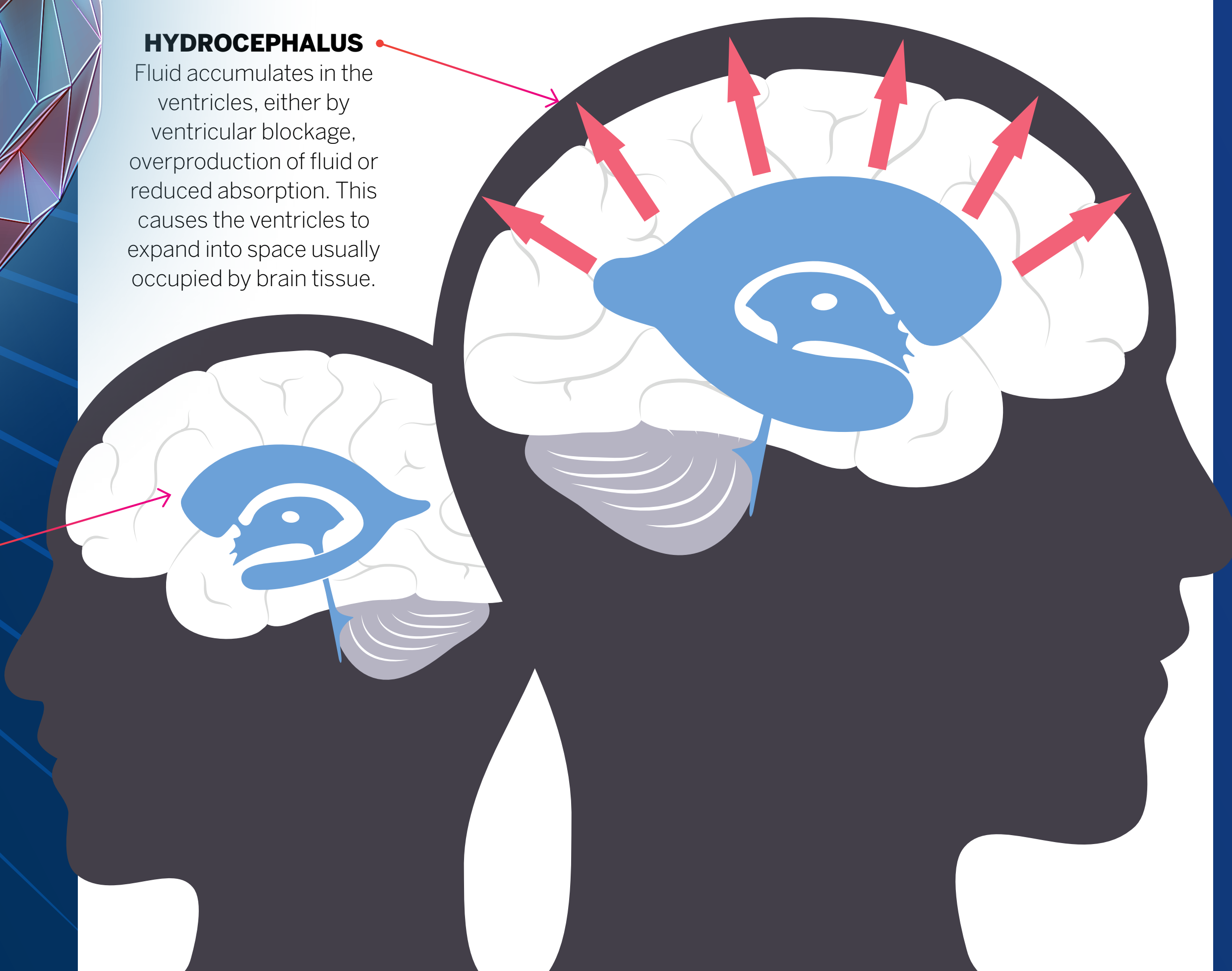
IT'S POSSIBLE TO LIVE WITHOUT MOST OF IT

01 In 2015, a team of neurologists and radiologists from Jinan Hospital in Shandong Province, China, wrote to the journal *Brain* reporting a rare and unusual finding. A 24-year-old female patient had been admitted with symptoms of nausea and vomiting. These were new symptoms, but she'd also suffered from dizziness and walking difficulties for most of her life. Despite these challenges, she was married and had enjoyed a successful pregnancy. The doctors referred her for computer tomography (CT) and magnetic resonance imaging (MRI) scans to search her brain for a cause of these symptoms. What they observed was a disorder so rare that less than ten people throughout the world were known to be living with it. The patient was completely missing her cerebellum.

Known as the 'little brain', the cerebellum is a distinct structure that sits at the back of the brain. It only occupies approximately ten per cent of brain volume but contains a dense abundance of neurons estimated to be well over 50 per cent of the total neurons in the brain. Together these neurons work to coordinate motor actions, allowing us to walk with balance and speak with precision. Despite the cerebellum's integral function, sufferers of cerebellar agenesis – where the structure is completely absent – are sometimes able to mentally develop normally aside from hampered motor functions.

Loss of brain tissue can also be seen in sufferers of hydrocephalus, a condition where cerebrospinal fluid accumulates in the brain. In extreme cases, the fluid can accumulate to such an extent that it doesn't leave much room in the skull for anything else, including brain matter. In Marseille, France, a 44-year-old male was found to be suffering from a case of hydrocephalus so severe that he was estimated to be missing over 50 per cent of his brain tissue. And yet the man had led a relatively normal life, maintaining a job and raising a family, showcasing the brain's incredible capacity to adapt and utilise what tissue it has to perform necessary functions.

HYDROCEPHALUS
Fluid accumulates in the ventricles, either by ventricular blockage, overproduction of fluid or reduced absorption. This causes the ventricles to expand into space usually occupied by brain tissue.



NORMAL
Cerebrospinal fluid moves throughout the brain via ventricles. The fluid's role is to protect the organ from shock, provide nutrients, remove waste material and regulate pressure.

WRINKLY BRAINS ARE SMARTER


Mice can problem-solve

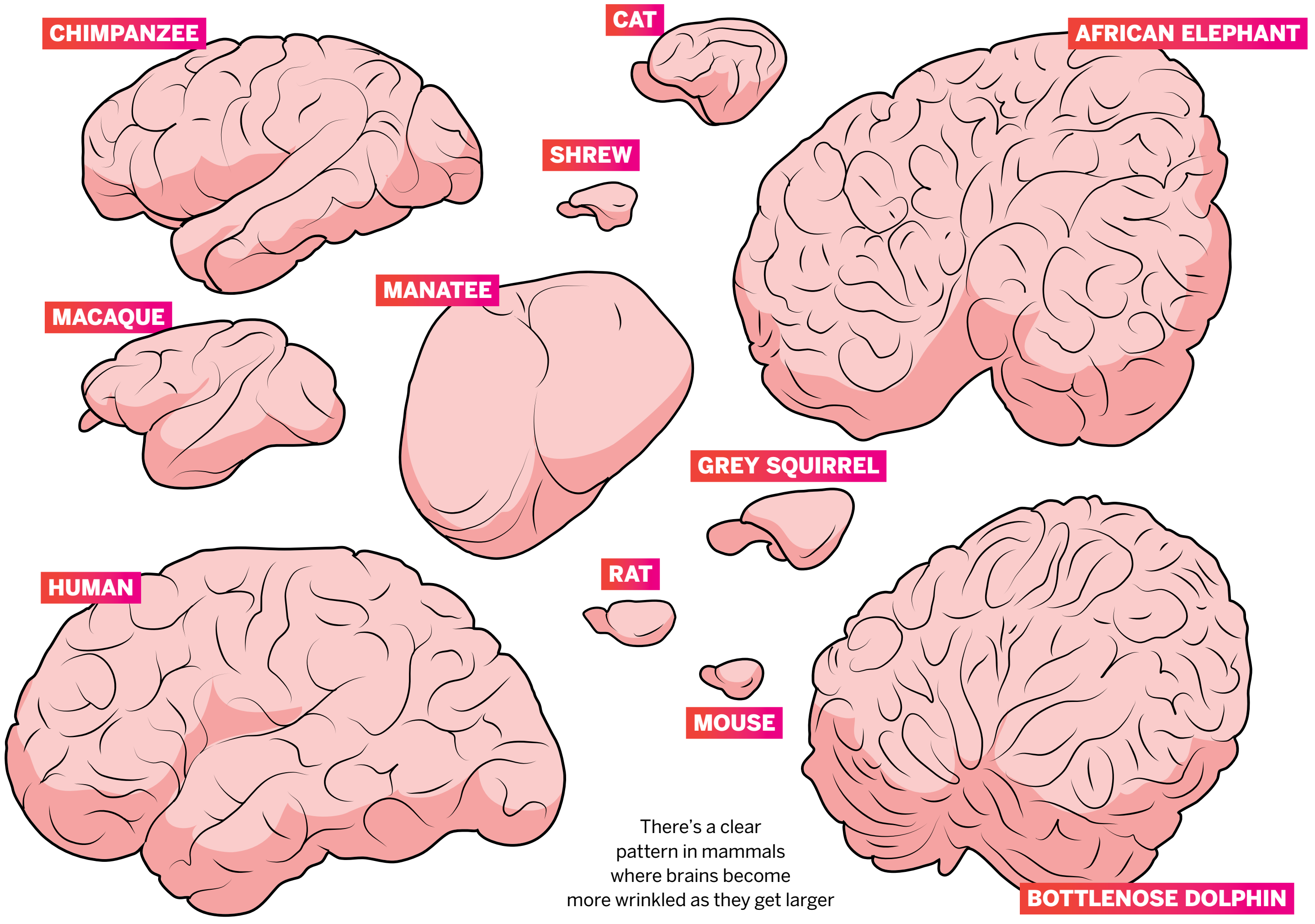

Dolphins are considered to be highly intelligent

02 Sometimes we encounter people who have a high opinion of their own intelligence, and we might call them 'big-headed'. This is because we naturally associate a big brain with high intelligence – that more brain means more thinking power. But it would be more accurate to call them 'wrinkly brained'. The exterior of the human brain isn't a shiny, smooth surface, but instead is a wrinkled mass of folds that form as a result of 'gyrification'. As we develop, our brains expand into a limited space defined by the available room in the cranium. To maximise the amount of brain within this limited space, the brain expands and then folds in on itself, forming layers of gyri (bumps) and sulci (grooves).

The result of gyrification is to increase the surface area of the brain. Increasing surface area in a limited space is a useful trick employed by biology all the time. Elsewhere in the human body, our lungs utilise tiny alveoli sacs and our gut uses finger-like villi to vastly increase the surface area available for exchanging gases and nutrients. The brain's high surface area allows it to pack as many brain cells, or neurons, inside our heads as possible.

In humans, a condition called lissencephaly, which describes when the brain is smooth and not wrinkled, causes severe and fatal mental development issues. However other mammals, such as mice and marmoset monkeys, are naturally lissencephalic. Typically, mammalian brains become more wrinkled as the brain becomes larger, meaning that larger rodents and primates possess gyrencephalic brains. But humans have neither the largest or the most wrinkled mammalian brain. In fact, the Atlantic bottlenose dolphin has a brain about the same mass as a human's but is nearly twice as wrinkled.

Humans do, however, have thicker layers of the brain, which may help explain our higher intelligence. While wrinkly brains usually mean bigger brains and are correlated with intelligence, there are other reasons for brain power hidden within their folds.



There's a clear pattern in mammals where brains become more wrinkled as they get larger

DID YOU KNOW? Flavonoids, which are found in dark chocolate, have been found to boost cognition in rodents and the elderly

Recently listening to a piece of music can trigger an involuntary slave response later

EARWORMS PROVE WE'RE SLAVES TO OUR BRAINS

03 Many functions controlled by the brain are autonomous and involuntary, such as breathing, digesting and shivering. But sometimes thoughts can be involuntary as well. One example of this is the 'earworm', where a song gets stuck in our head. In 1974, a research paper by Alan Baddeley and colleagues proposed the idea of 'working memory', which describes how we possess a small store of information that can be rapidly drawn upon to form decisions. In service of the working memory are the 'slave systems' which store audio-visual information and verbal information respectively. The verbal information slave system has a component known as the 'phonological loop' which can store short tracts of audio and rehearse them. This essentially builds an involuntary 'replay audio' button in our working memory. More recent research has additionally found that involuntary earworms can be triggered by recently listening to the offending piece of audio or by observing a different audio or visual cue that is associated with the memory of the song or sound. This means that a catchy song can be recalled and played on a loop entirely autonomously, even when we'd rather be rid of it.

04 YOUR BRAIN IS CONSTANTLY TRYING TO TRICK YOU WITH THESE WEIRD PHENOMENA

LETHOLOGICA

In the middle of a conversation, our sentence stalls. We stop talking and search our brain for a word that isn't there. This is lethologica, when a word is at the tip of your tongue. We know what we want to say and know there's a word that fits, but we can't recall it because our memory has faltered. This is thought to happen more often with words that we don't use, because we haven't built strong recall connections with these words. Adults are believed to have an average of 50,000 words in their vocabulary, so lethologica could happen with many of them.

DÉJÀ VU

The sensation of déjà vu, French for 'already seen', describes times when we feel as if we've already experienced the present moment. For psychiatric patients déjà vu is often associated with anxiety, but around two-thirds of individuals also experience the sensation regularly. Déjà vu occurs when our brain makes a false familiarity with a new stimulus. This results in the construction of an artificial memory that triggers the sensation. Research suggests we're more likely to experience déjà vu when we go to new places and have new experiences.

Did you know?

Exercise can boost your brain power

MISOPHONIA

Sufferers of misophonia are sensitive to certain sound patterns that others pay no heed to, causing symptoms such as anxiety or anger. The sound of chewing is a common culprit of this, but foot tapping or the sound of a clock ticking can also trigger a response. Strangely, patients have reported that the subtle nature of these stimuli is what makes them potently irritating. The cause of the condition is not currently fully understood, but there are certain parallels with triggers observed in sufferers of Tourette's syndrome and obsessive-compulsive disorder.

THE DOORWAY EFFECT

It can be irritating when you walk into a room and forget the reason why you entered in the first place. It's a consequence of the way our brain assembles and maintains memory. When we walk through a door, our memory passes through what researchers term an 'event boundary', which is when the currently experienced 'event' is banked into long-term memory as the next event begins. However, not all the banked information is retained for immediate recall. This means that when we pass through the door and go through an event boundary, our reason for entering the room can be lost from our working memory.

THE BRAIN IS MOSTLY WATER AND FAT

05 Many organs of the human body are mostly water, and the brain is no different. The other compounds – including fats, proteins, carbohydrates and others – only make up about a quarter of our brain material. However, a brain's dry weight shows that fat is the dominant structural element of the brain. These aren't just the sorts of saturated fats you'd find in your favourite takeout or snack, but types of lipids, including cholesterol and fatty acids, that are used to form myelin.

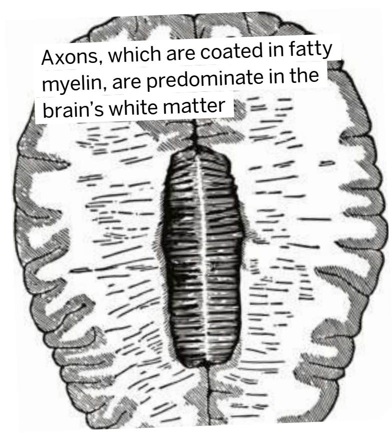
Myelin is a structure made up of approximately 80 per cent lipids and 20 per cent protein and is found wrapped around parts of our brain cells, known as neurons. Neurons are composed of three main structural elements, including dendrites, which receive electrical signals from neighbouring cells. The cell body, also known as a soma, contains genetic information and provides the cell with energy. Axons carry electrical impulses away from the cell towards neighbouring neurons. Like electrical wiring in our homes, axons require an insulating sheath to protect the cell and ensure that the signal remains strong and moving in the desired direction. Myelin sheaths are used for this task, meaning neurons with long axons harbour a lot of fatty material.

The brain possesses a rich abundance of axons – so many that myelin-dense areas change the colour of the brain on scans, turning it white rather than grey. Grey matter, which is found around the periphery of the brain, is mostly composed of soma. Matter, however, consists mostly of axons and their fatty coatings of myelin. While the brain might be surprisingly fatty, without lipids it simply wouldn't be able to function.

COMPOSITION

WATER:	~76%
LIPIDS (FATS):	~12%
PROTEINS:	~8%
CARBOHYDRATES:	~1%
SOLUBLE ORGANIC SUBSTANCES:	~2%
INORGANIC SALTS:	~1%

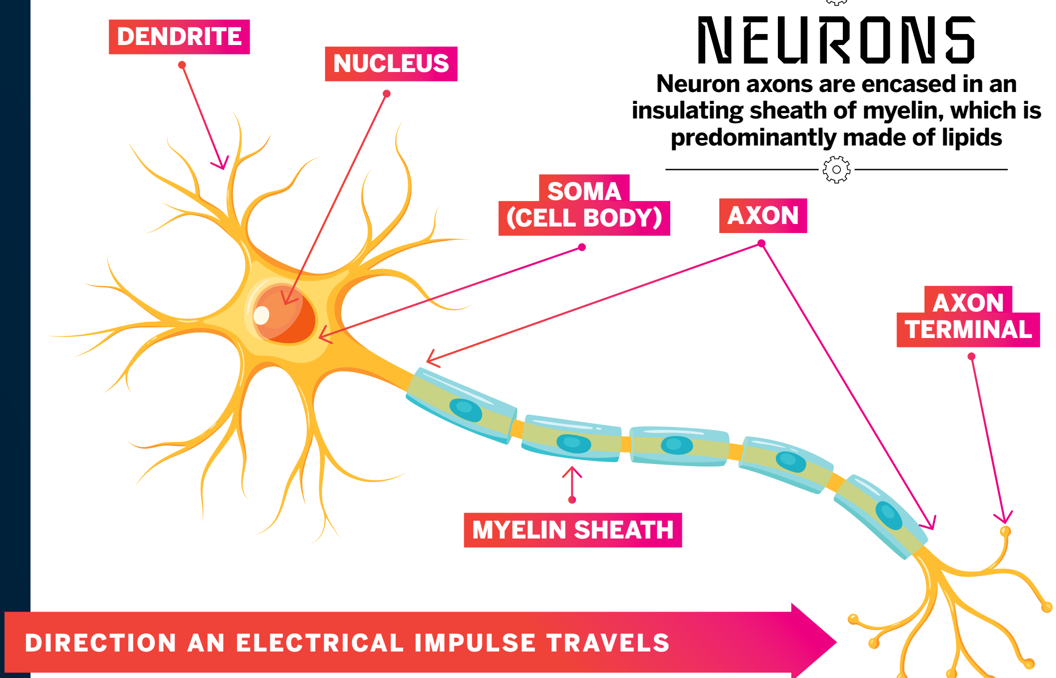
Did you know?
An adult male's brain weighs between 1.3 and 1.4 kilograms

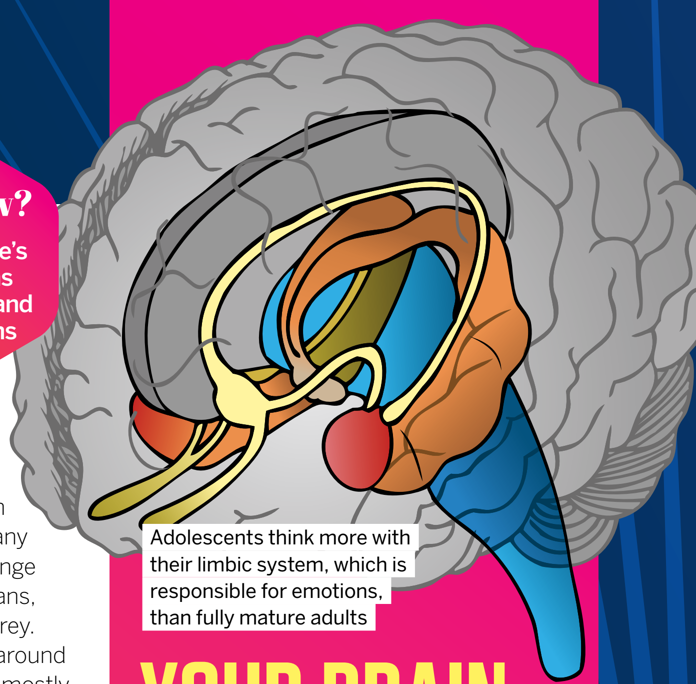


Axons, which are coated in fatty myelin, are predominate in the brain's white matter

NEURONS

Neuron axons are encased in an insulating sheath of myelin, which is predominantly made of lipids





Adolescents think more with their limbic system, which is responsible for emotions, than fully mature adults

YOUR BRAIN ISN'T FULLY DEVELOPED UNTIL YOU'RE 25

06 Our brain reaches nearly full volume inside the cranium within the first few years of life, but the regions of the brain still require considerable development. These major regions are each associated with controlling certain behaviours and emotions, and throughout childhood and adolescence they develop at different rates, reaching maturity at different times. By the time we're 25, it's widely considered that all regions of the brain have reached maturity, but prior to this time we go through periods where the development is unbalanced, leading to different behavioural traits.

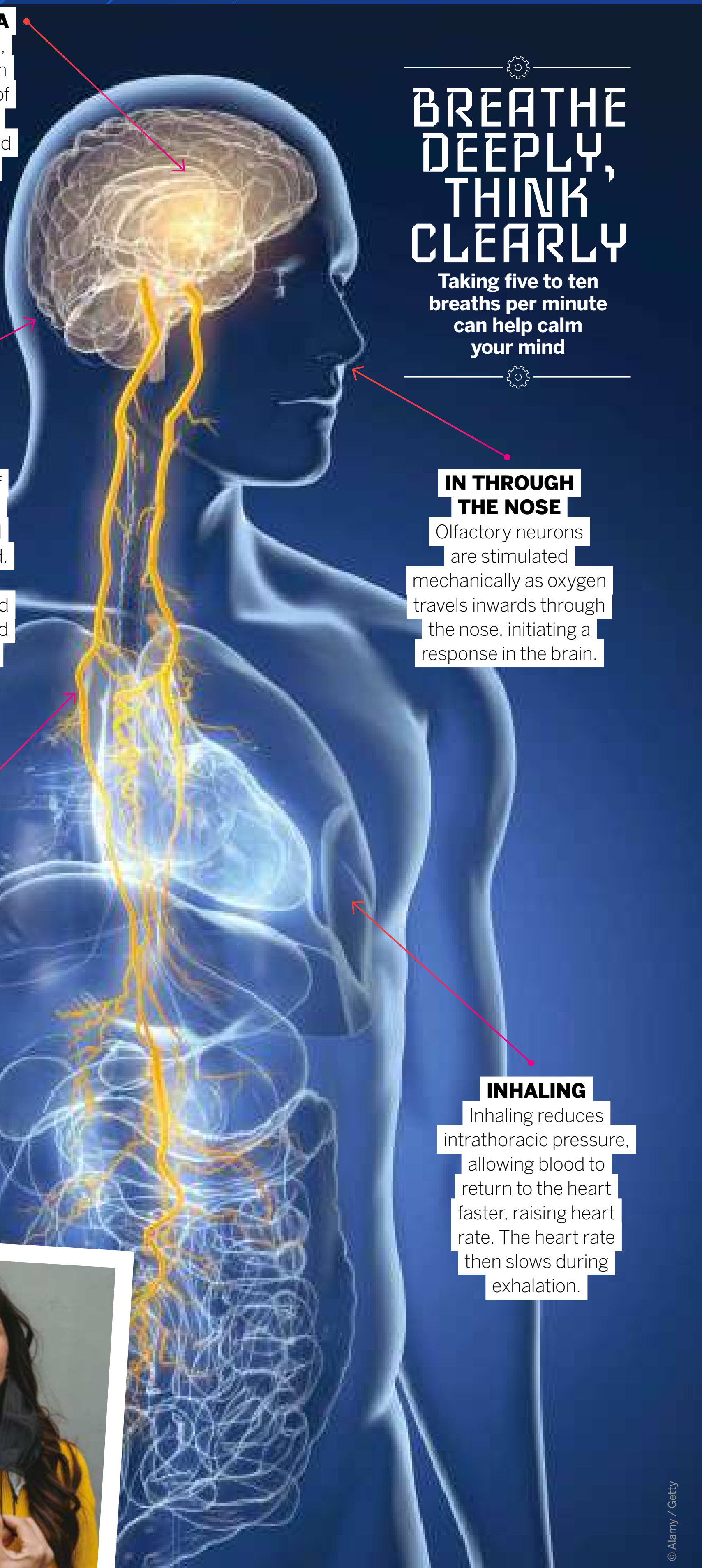
As the brain's grey matter develops from back to front, the prefrontal cortex at the top-front of the brain is one of the last regions to reach maturity. Unfortunately for parents wishing to reason with their teenage children, the prefrontal cortex is responsible for rational judgement and long-term planning. Instead, as the region has not yet fully developed, adolescents operate primarily at the behest of their limbic system, which is responsible for emotions. As a result of this, adolescents are prone to take more risks and tend to fixate more on the present moment – their emotions rule over rationality.

DEEP BREATHING AIDS THINKING

07 It's long been understood that the brain regulates breathing. The brain stem, which sits at the base of the brain near the spine, regulates the autonomic nervous system that controls automatic functions such as heart rate, digestion and breathing. Less understood is that this process can operate as a feedback loop – breathing can also regulate brain activity.

In 2016, a team demonstrated this phenomenon by performing an experiment using epileptic patients that had been prepped for surgery. The patients had already been fitted with electrode implants so that their surgeon could locate the origin of their seizures, allowing the researchers to accurately measure the activity of certain brain regions throughout the experiment. The regions of interest were those responsible for responding to olfactory nerves found up our nose (the piriform cortex), a region responsible for memory (the hippocampus) and a region responsible for emotion (the amygdala). The research team also equipped the patients with sensors to monitor their breathing.

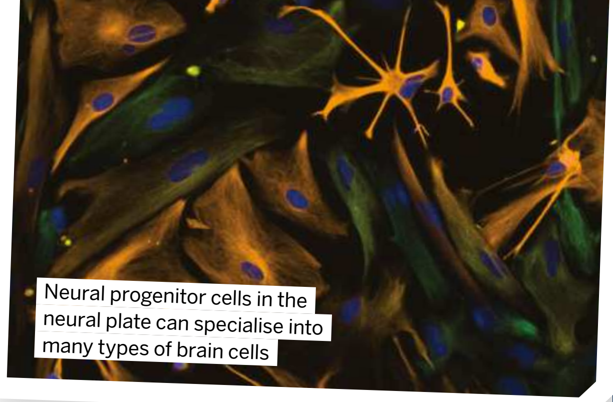
Amazingly, the team observed that all three studied regions of the brain responded to the stimulus of breathing. This effect wasn't strong for all phases of breathing, but primarily during inhalation through the nose. Exhaling and mouth breathing did not cause the same effect. The researchers next asked the patients to identify emotions being displayed by a person using still images and also set them a visual memory task. They observed that both the emotion-based task and the memory task were completed more accurately when the patient was challenged for a response while breathing in. This showed that not only do brain patterns change while inhaling through the nose, but that cognitive ability is enhanced while breathing in relative to other states.



BREATHE DEEPLY, THINK CLEARLY

Taking five to ten breaths per minute can help calm your mind


Research has shown that inhaling through the nose provides enhanced cognitive function over exhalation

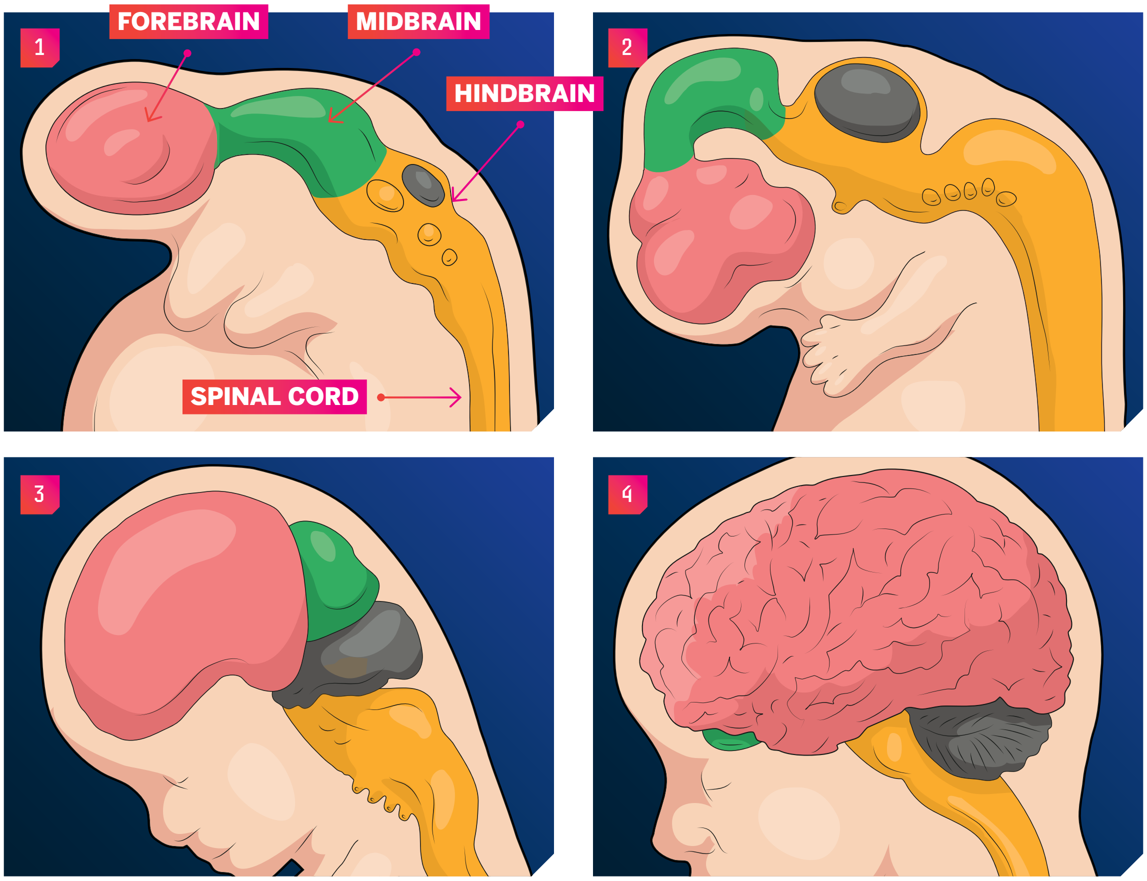


Neural progenitor cells in the neural plate can specialise into many types of brain cells

YOUR BRAIN BEGINS AS A TUBE

08 Neural development begins very early in the growth of an embryo. The central nervous system begins its existence from one structure, starting as a sheet of cells known as the neural plate. A few weeks following conception, the neural plate begins to form ridges and folds in on itself, becoming a tube structure. From here the neural progenitor cells of the tube, which can differentiate and specialise into numerous brain cell types, begin to proliferate in a highly structured manner to mature the neural tube into the developed brain. The cavity inside the hollow tube remains, eventually becoming a ventricular space that will hold the cerebrospinal fluid that protects and nourishes the cells of the brain.

The expansive network of connections between neurons continues to develop throughout gestation as the brain grows, continuing long after birth. However, a foetus is capable of some cognitive function even during these early stages. By week 30 the pathways responsible for recognising pain are connected. While the foetus remains unconscious throughout most of its development, when awake it will eventually be able to recognise touch, smells, sounds and alter its facial expressions in response to these external stimuli. These responses are innate and non-conscious, but numerous studies have reported that babies can remember and recognise audio heard as a foetus from the womb, when the sounds were muffled and dampened but still audible. Newborn brains also come equipped with innate reflexes and behaviours to help the baby survive in the big wide world. Despite poor vision, they learn to recognise their mother's face almost immediately. They can determine the difference in touch between self and others and they can display emotions. It's just a slight shame that initially most of these displayed emotions often involve screaming and crying.



1 3 WEEKS
The budding brain starts off as the tip of a three-millimetre tube. This forms the beginnings of the forebrain, midbrain and hindbrain.

2 7 WEEKS
The regions continue to differentiate and expand. Buds of cranial nerves that will eventually connect the brain to the face, neck and torso begin to appear.

3 11 WEEKS
The rapidly growing forebrain becomes much larger than the other regions. At this stage, the forebrain is still smooth.

4 BIRTH
The forebrain expands and wrinkles, enveloping the midbrain. The hindbrain develops into the cerebellum and part of the brain stem.

REALITY-BENDING BRAIN DISORDERS

CAPGRAS DELUSION
Sufferers of this condition recognise their loved ones but do not believe them to be who they are. They become convinced that they've been replaced by imposters, robots or aliens. The condition has been seen in patients suffering from paranoid schizophrenia, dementia and brain injury.

ALIEN HAND SYNDROME
Also known as anarchic hand, patients with this condition lose full control of one of their hands, which periodically goes rogue. The rebellious hand appears to ignore orders from the brain and can reach, grasp and swipe. Patients can become convinced their hand belongs to someone else entirely.

FOREIGN ACCENT SYNDROME
Following a stroke that affects speech, a rare neurological condition can occur wherein the patient recovers their speech ability in a foreign accent. This can occur even if they've never visited the country.

COTARD'S SYNDROME
Sometimes referred to as walking corpse syndrome, sufferers of this affliction think that they are dead. This can follow a depressive episode where the person stops feeling pleasure and is overcome by feelings of worthlessness and can sometimes be treated with antidepressants.

DID YOU KNOW? When an embryo is 12 to 14 weeks old, its neurons proliferate at a rate of approximately 15 million per hour

STONE-AGE PEOPLE CONDUCTED BRAIN SURGERY SUCCESSFULLY

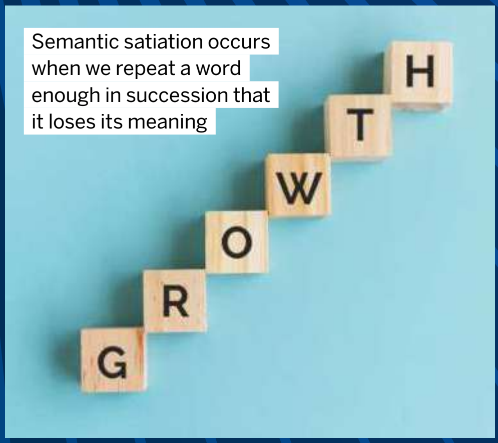
The process of trepanation was used in ancient times to treat numerous ailments, and over time the skull could heal

09 In 1996, a skeleton was unearthed from a Neolithic burial site in Alsace, France. The skeleton belonged to a man around 50 years of age who was believed to have died around 5000 BCE. Despite living 7,000 years ago, the man underwent surgery on his skull and survived for some time afterwards. The researchers who recovered his skull noticed that roughly circular pieces of it had been surgically removed in two places, which is known as trepanation. One segment was around 6.5 centimetres long, and the other around 9.5 centimetres long. While the reason for him undergoing these surgeries is unknown, other ancient cultures used trepanation as a treatment for ailments such as headaches, epilepsy and mental illnesses. The surgery carried numerous risks, including haemorrhage, brain damage and infection, yet the researchers determined that the man survived for at least a decent period after the procedures. The bone around one of the trepanation holes had partially healed, while the other had fully healed, sealing the hole completely.

Trepanation has been practised across the ages in many cultures

Did you know? The brain uses about 20 per cent of our oxygen intake

IF YOU REPEAT SOMETHING ENOUGH, IT LOSES MEANING



Semantic satiation occurs when we repeat a word enough in succession that it loses its meaning

10 Words are the product of when our brains connect a particular sound to a specific meaning. Our brains are incredibly adept at maintaining this connection, providing us the power of language and the means to readily communicate complex ideas with another human that shares this knowledge. However, we can temporarily but rapidly sever the connection between sound and meaning, and we can do this simply by repeating a word. This effect is known as semantic satiation, where repetition strips a word of its meaning and renders it just a sound. You may have encountered this effect when vocalising a word over and over, perhaps when practising saying it or demonstrating its phonetics. Semantic satiation is believed to be caused by saturation of the brain with the same input, lessening the effect of the input to the point where it has no effect.

5 BRAIN MYTHS BUSTED

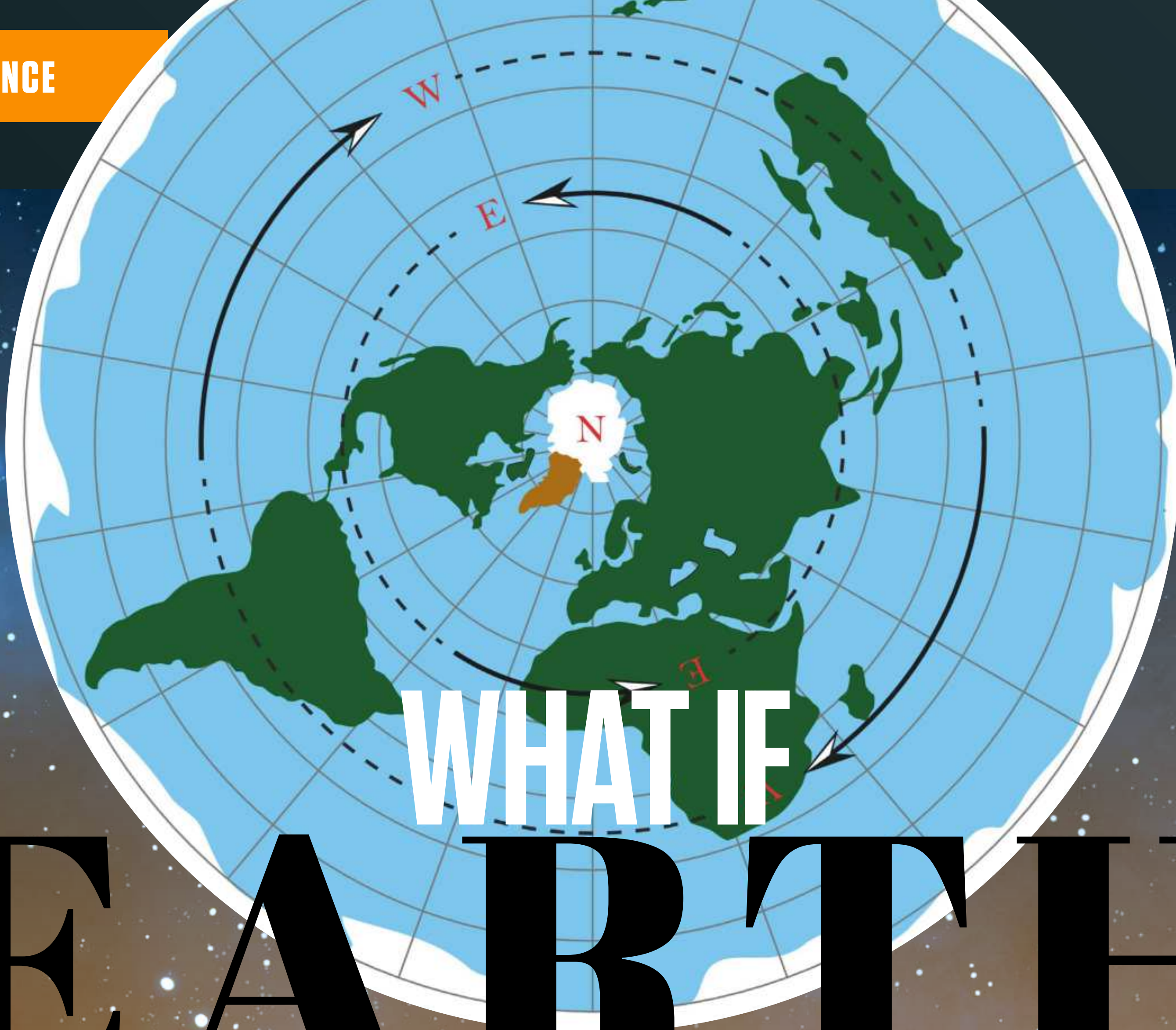
1 TEN PER CENT
While neurons may be heavily outnumbered by other brain cells, we employ much more than ten per cent of our brain for almost all actions, even for simple ones such as gripping an item.

2 MALE VS FEMALE
Males and females have historically been attributed to have different cognitive abilities for certain tasks, but recent studies show this isn't the case. For example, a study looking at maths ability in children from 68 countries found no differences between the two sexes.

3 TEACH AN OLD DOG NEW TRICKS
While people may become unwilling to learn new skills when they grow older, the neurons in their brains are still able to form new connections, so they remain able to learn, permitting the desire is there.

4 BIGGER THAN OUR ANCESTORS
We may feel smarter than any humans who came before us, but counterintuitively our brains are around ten per cent smaller than our ancestors' from several millennia ago.

5 BRAIN FOG ISN'T REAL
Although it isn't a medical term, brain fog describes when the brain's usual clarity is lacking, causing forgetfulness, confusion and slower mental processing.



WHAT IF EARTH WAS FLAT?

Eight ways our world would get weird if we really lived on a disc

WORDS **DAISY DOBRIJEVIC**

Earth – the Blue Marble – is our very much spherical home. Humankind has been aware of this for more than 2,000 years, ever since the ancient Greek academic Pythagoras proposed its spherical shape back in 500 BCE. Eratosthenes then calculated its circumference around 240 BCE. But let's imagine that Earth is flat. After all, there are many out there who truly believe that this is the case. How would everyday life function? Would it function at all? Here we explore how much of an oddball – or 'oddslice' – Earth would be if it were flat and whether there are any advantages to living on a strange disc with the Sun and Moon rotating overhead like characters on a cosmic carousel.

DID YOU KNOW? At the equator, the circumference of Earth is around 25,000 miles

NO MORE AURORAE, AND WE'D ALL BE ROASTED

1

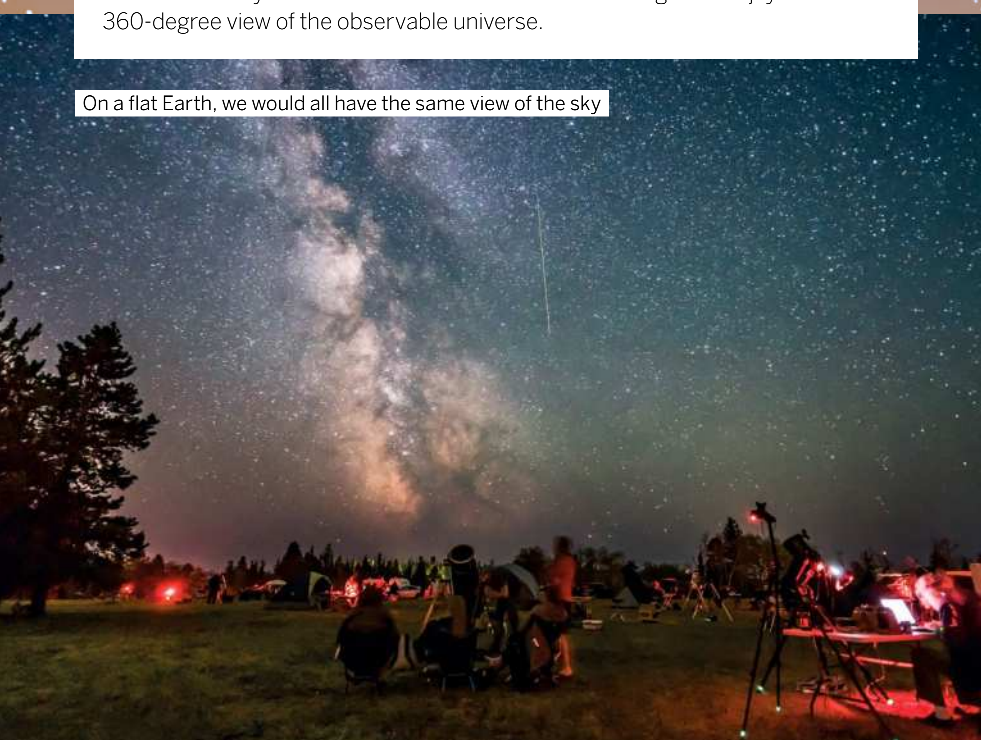
On spherical Earth, the swirling molten metal surrounding our iron core generates electric currents, which in turn create our protective magnetic field, curving around the planet from one pole to the other. But on a flat Earth, without a solid core generating a magnetic field, we would lose our protective layer, called the magnetosphere. Charged particles from the Sun would no longer interact with our magnetosphere to create incredible auroral light shows. Though the absence of aurorae would be the least of our worries, as Earth would no longer be protected from the solar wind. We'd be bombarded with harmful solar radiation that could strip Earth of its protective atmosphere, leaving a barren world akin to our neighbour, Mars.


Aurora photographed by NASA astronaut Jack Fischer aboard the International Space Station

EVERYONE WOULD SHARE THE SAME VIEWS OF THE NIGHT SKY

2

On a flat Earth there would be no Northern or Southern Hemisphere, and our night sky would look the same wherever you were in the world. It sure would make stargazing easier, as you wouldn't have to travel to a different hemisphere to tick off all the targets on your astronomy bucket list. But isn't that all part of the fun? If we all shared one view of just one portion of the night sky, we'd miss out on the many discoveries that have been made through our enjoyment of a 360-degree view of the observable universe.


On a flat Earth, we would all have the same view of the sky


Hurricane Florence photographed from the ISS

3

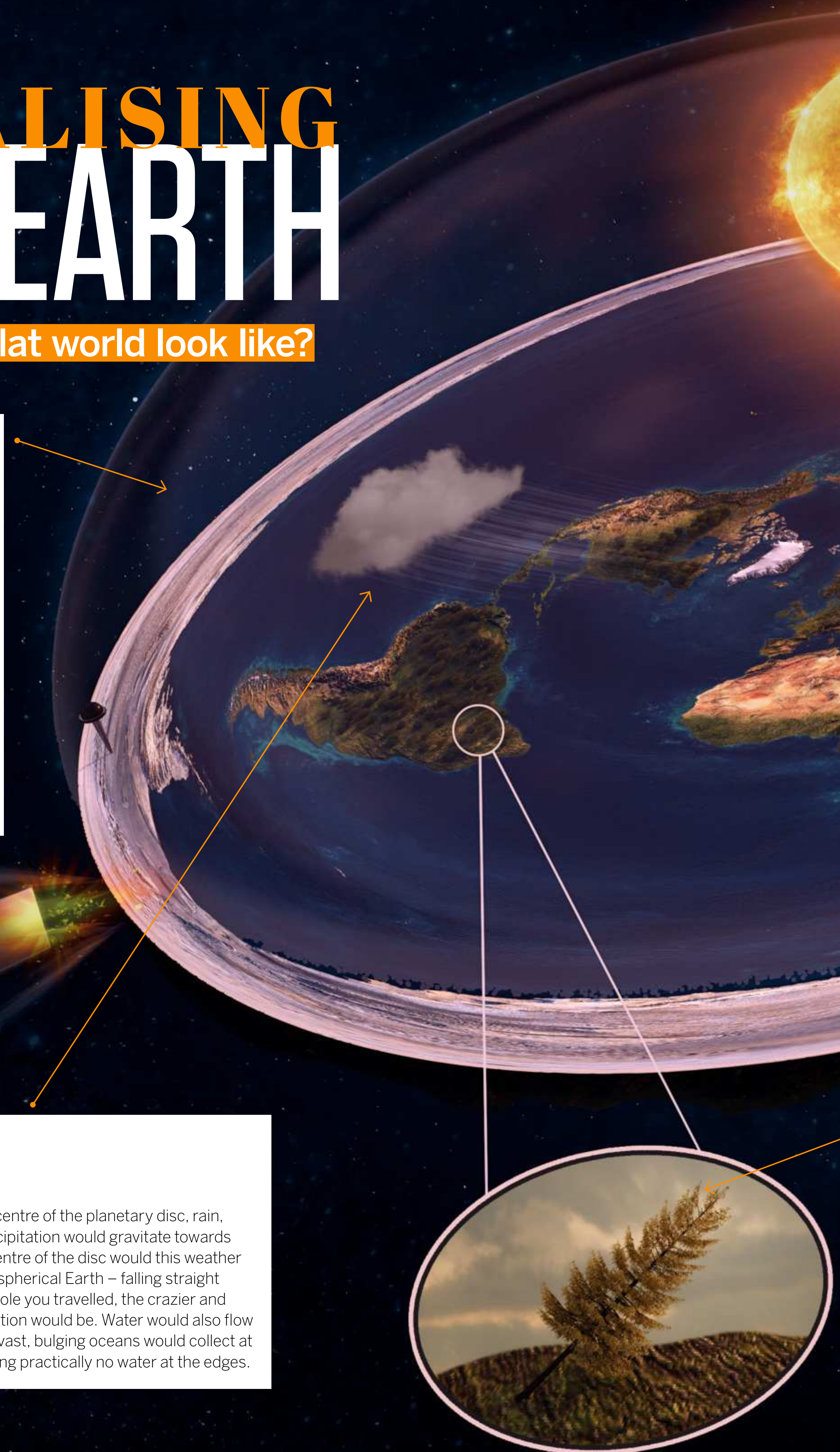
HURRICANES WOULD BE A THING OF THE PAST

Every year, hurricanes, formed over the North Atlantic and Northeast Pacific; typhoons, formed over the Northwest Pacific, and cyclones, formed over the South Pacific and Indian Oceans, cause unprecedented damage. In 2017 Hurricane Harvey alone caused $125 billion (£90 billion) worth of damage in the US.

The devastating rotating nature of these tropical storms stems from Earth's Coriolis force, which causes those in the Northern Hemisphere to rotate clockwise and those in the Southern Hemisphere to rotate counterclockwise. However, on a stationary, flat Earth, no Coriolis force would be generated. No Coriolis means no hurricanes, typhoons or cyclones. This is also why we don't see these storms between five degrees north and south of the equator, as the Coriolis magnitude is zero at the equator.

VISUALISING FLAT EARTH

What would a flat world look like?



WE'D HAVE NO ATMOSPHERE 5

With no gravity, flat Earth would no longer be able to hold onto an atmosphere. Without our planet's protective blanket our skies would turn black, and surface life would cease to exist.

Water would boil away in the vacuum of space, and surface temperatures would plummet. But it isn't all bad news. Deep ocean-dwelling organisms that don't require oxygen (anaerobic bacteria) and those that don't need sunlight to generate food and energy (chemosynthetic bacteria) might just survive. After all, such bacteria have endured long trips in space and lived to tell the tale.

SIDEWAYS RAIN 6

If gravity pulled towards the centre of the planetary disc, rain, snow and other forms of precipitation would gravitate towards the North Pole. Only at the centre of the disc would this weather behave as we know it on our spherical Earth – falling straight down. The further from the pole you travelled, the crazier and more horizontal the precipitation would be. Water would also flow towards the North Pole, and vast, bulging oceans would collect at the centre of the planet, leaving practically no water at the edges.

DID YOU KNOW? For someone 183 centimetres tall, the horizon is just over three miles away

7 WE WOULD ALL GET LOST

It's very likely that satellites wouldn't exist if Earth were flat, as they would have trouble orbiting a flat plane. "There are a number of satellite missions that society depends on that just wouldn't work," says James Davis, a geophysicist at Columbia University's Lamont-Doherty Earth Observatory. "I cannot think of how GPS would work on a flat Earth."

We depend on Global Navigation Satellite Systems (GNSS) for everything from the GPS services on your phone to travel information and supermarket stock management to make sure produce arrives as fresh and as quickly as possible. And, critically, emergency services use GPS to locate callers from their phone signal – so satellite communications could possibly save your life.

It's hard to imagine a world without GPS. Suffice to say we'd be lost without it. On the upside, at least on a flat Earth we'd have the horizontal rain to point us in the right direction – or north, at least.

4 SAY GOODBYE TO GRAVITY… AT LEAST AS WE KNOW IT

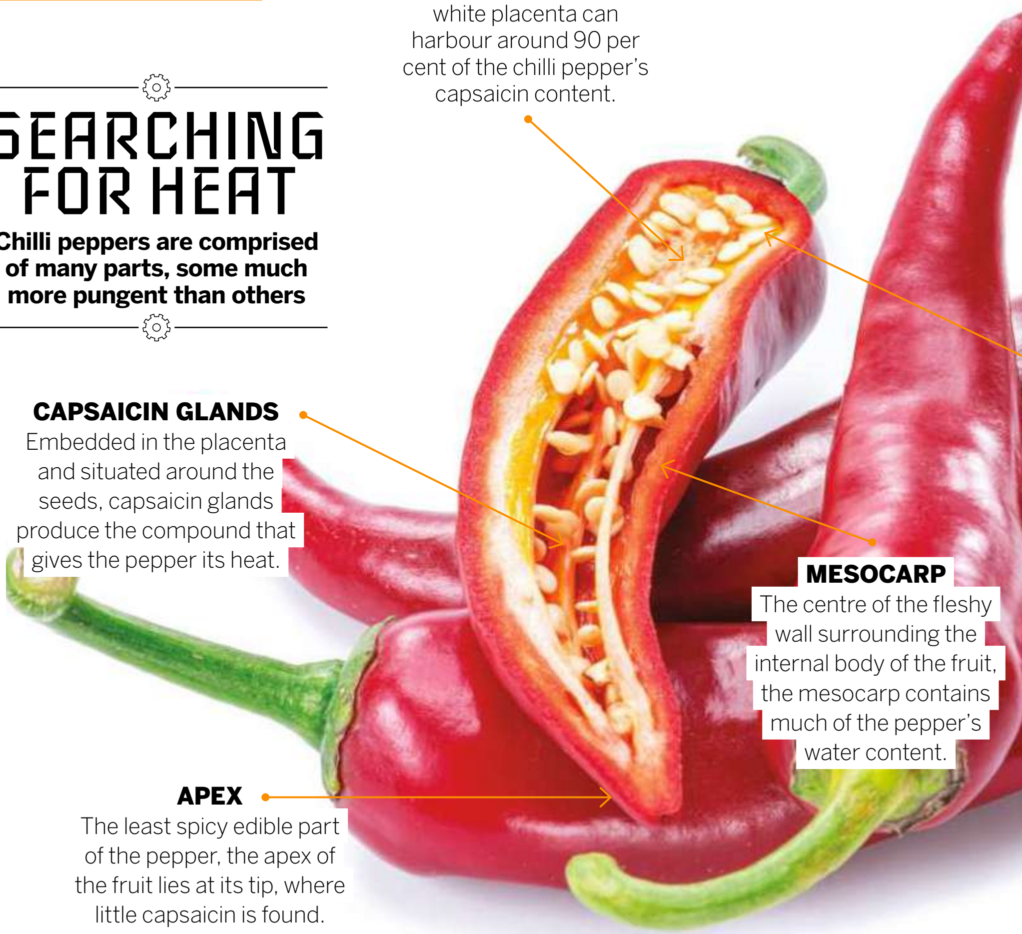
On spherical Earth gravity pulls equally from all sides no matter where in the world you are. For Earth to take the shape of a disc in the first place, gravity must be having no effect. If it did, it would soon pull the planet back into a spheroid. Maybe a flat Earth would have no gravity at all. Or perhaps a flat Earth would cause gravity to pull to the centre of the disc: the North Pole. The further away from the North Pole, the more horizontal the gravitational tug. This would wreak havoc worldwide, but at least the world long jump record would be easily beaten – as long as you orientated yourself northwards before taking off.

8 SOME JOURNEYS WOULD TAKE FOREVER

Longer travel times would be expected, not just from getting lost due to a lack of GPS, but also the distances we would need to travel. According to flat Earth belief, the Arctic lies in the centre of the planet, and Antarctica forms a giant 'ice wall' around the edge, which conveniently stops people falling off. But if you're unable to fly around the globe, and instead are forced to fly 'across' it, then travel times significantly increase. For example, to fly from Australia, which is on one side of the flat Earth map, to a part of Antarctica that lies on the other side, you'd need to fly across the whole Arctic, as well as North and South America. You can also forget about trips across Antarctica – which has been achieved – as it'd be impossible due to that pesky ice wall.

SEARCHING FOR HEAT

Chilli peppers are comprised of many parts, some much more pungent than others




The Carolina reaper is the world's hottest pepper at 2.2 million Scoville heat units


Milk contains a protein called casein that can carry away capsaicin, making it much more effective at combating spice than water

WHAT MAKES CHILLI PEPPERS SPICY?

Meet the tasty chemical compounds that pull sweat from foreheads, force tears from eyes and make tongues feel like they're on fire

WORDS **JAMES HORTON**

Spices have been part of human diets for thousands of years, and chilli peppers are now staple ingredients in many parts of the world. Chilli peppers are fruits and are part of the nightshade family, which contains members such as tomatoes, avocados and potatoes. Within this family lies the genus *Capsicum* that hosts peppers, a group of related species that are carefully cultivated to produce fruits with a spectrum of flavour and heat. From the mild bell pepper and the lively jalapeño to the unrelenting brutality of the Trinidad Moruga scorpion and Carolina reaper, peppers come in all ranges of spiciness. The heat, or pungency, of a chilli pepper is a product of its DNA, the environment it's grown in and its ripeness. DNA can be changed by cross-breeding two species, followed by selective breeding of the offspring where the progeny with the desired traits are bred further. The stress imposed on the pepper, such as the temperature it's grown in and the amount of water available to it, can likewise affect its pungency. Peppers also become spicier as they ripen from green to red.

While humans have learnt to manipulate and enrich pepper qualities, their spicy trait first evolved naturally as a defence mechanism. Rodents and mammals are equipped with receptors in their mouths that recognise the compound capsaicin – and other compounds collectively known as capsaicinoids – produced within chilli peppers. Capsaicin surrounds the seeds, which are needed for the plant to germinate its progeny, and the compound triggers the sensation of burning when consumed. This helps dissuade rodents and mammals from eating too much, with the latter being particularly threatening to the plant as they can grind and destroy the seeds as they eat the fruit. But birds, which do not grind the seeds and instead are useful helpers in dispersing them, are not sensitive to capsaicin and so are not discouraged from feeding. Capsaicin also wards off microorganisms from invading and decomposing the plant matter from the inside.

If capsaicin production and its spicy heat have evolved to deter hungry mammals from munching through peppers, then why do many humans ravenously ingest them? Spice serves a practical role in food by helping to prevent spoilage, but many of us who enjoy spice also like the challenging heat. While capsaicin triggers the sensation of burning and all its accompanying symptoms, such as sweating and mouth breathing, it can also trigger

Did you know?

Eating spicy foods can change your gut flora

THE SCOVILLE SCALE

In 1912, Wilbur Scoville created the Scoville Organoleptic Test as a means of measuring the amount of heat in a pepper. The method he developed was part quantitative and part subjective. Scoville gathered taste testers and asked them to taste a pepper's capsaicin content – dissolved in an alcohol solution – mixed with sugar water. The capsaicin solution would be continually diluted with sugar water until heat could no longer be detected, which provided Scoville heat units (SHU). A pepper measuring 5,000 SHU would need to be diluted by 5,000 before no heat could be detected. Jalapeños measure between 3,000 and 10,000 SHU, whereas pure capsaicin measures 16,000,000.

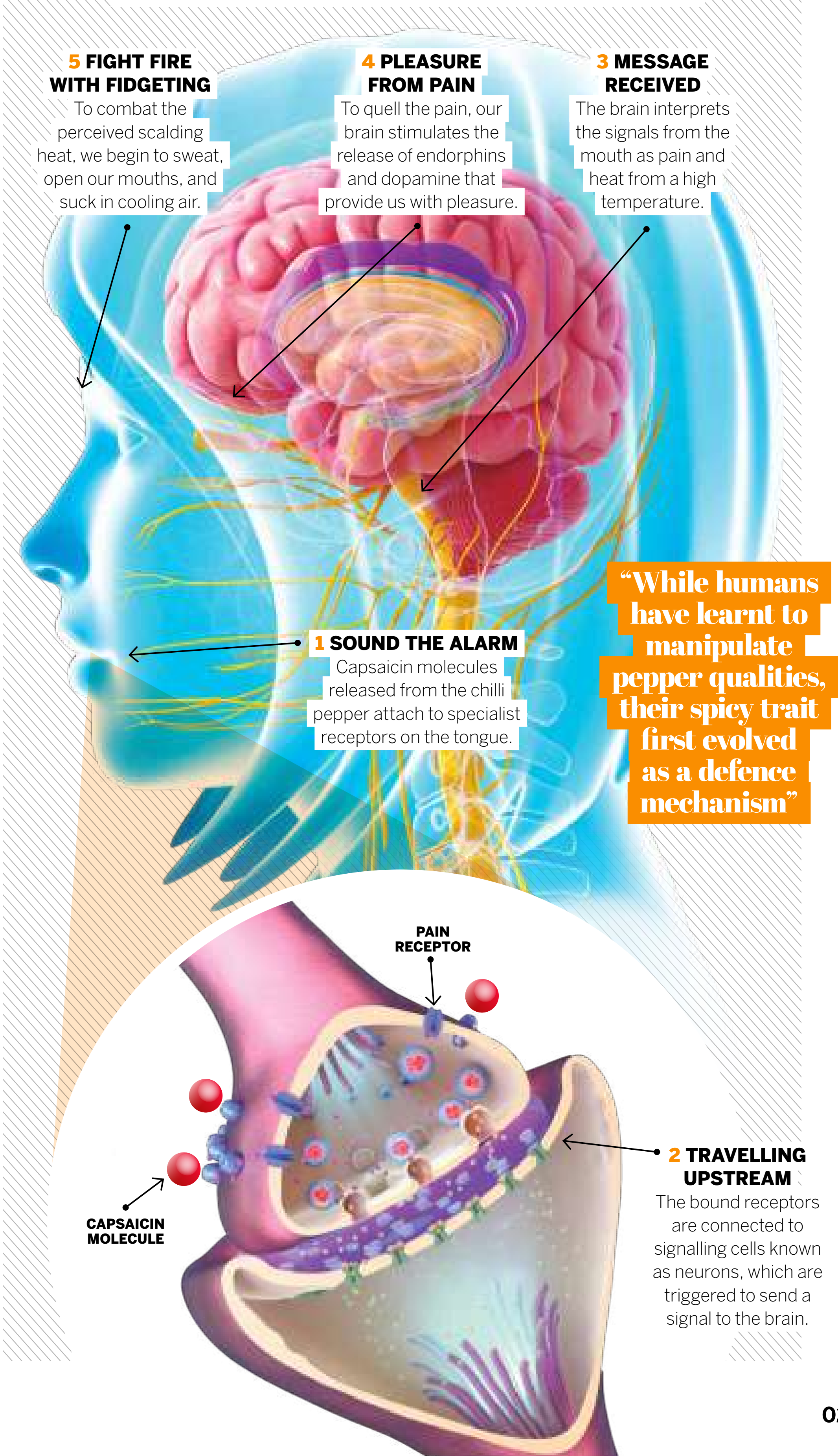
Scoville was a chemist who invented the scale measuring pepper pungency

the release of endorphins that provide pleasure as a means to combat the pain.

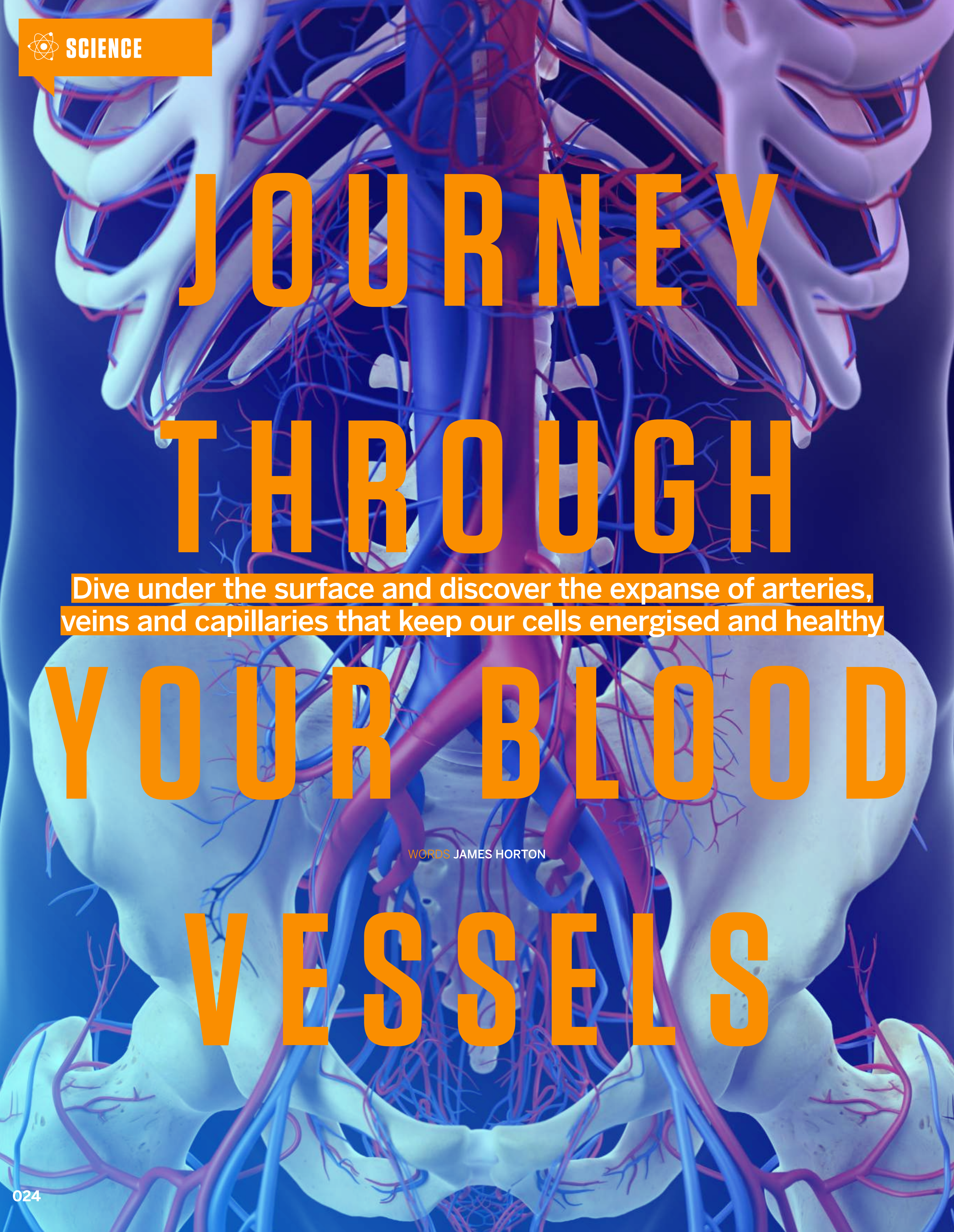
However, the pleasure of eating spice is not there for all of us. The endorphin release does not happen for everyone equally, and for those who are sensitive to spice – or for spice lovers who overindulge – the pleasure can quickly recede while the pain intensifies. Unfortunately, the damage of too much spice doesn't end in our mouths, as capsaicin can bind to receptors in our stomach and intestines. This can trigger diarrhoea as our body acts to protect itself by rapidly funnelling the irritant compound through the gut as quickly as possible. And in a case of true polar symmetry, the receptors that interpret capsaicin as heat at the beginning of our gastrointestinal tract are also there at the end, which is why we can also feel burning as we eliminate stool. Finally, as capsaicin is an irritant that also affects our outer organs, the abundant compounds in the spiciest peppers can elicit burning sensations when they come into contact with our skin and eyes. Chilli peppers can be as delicious as they can be harmful; the experience we have when eating them is determined by our tolerance – and the amount of capsaicin putting our receptors to the challenge.

FEEL THE BURN

The presence of capsaicin provokes a reaction from our brain as if we've come into contact with a high-temperature food



> **"While humans have learnt to manipulate pepper qualities, their spicy trait first evolved as a defence mechanism"**



JOURNEY THROUGH YOUR BLOOD VESSELS

Dive under the surface and discover the expanse of arteries, veins and capillaries that keep our cells energised and healthy

WORDS JAMES HORTON

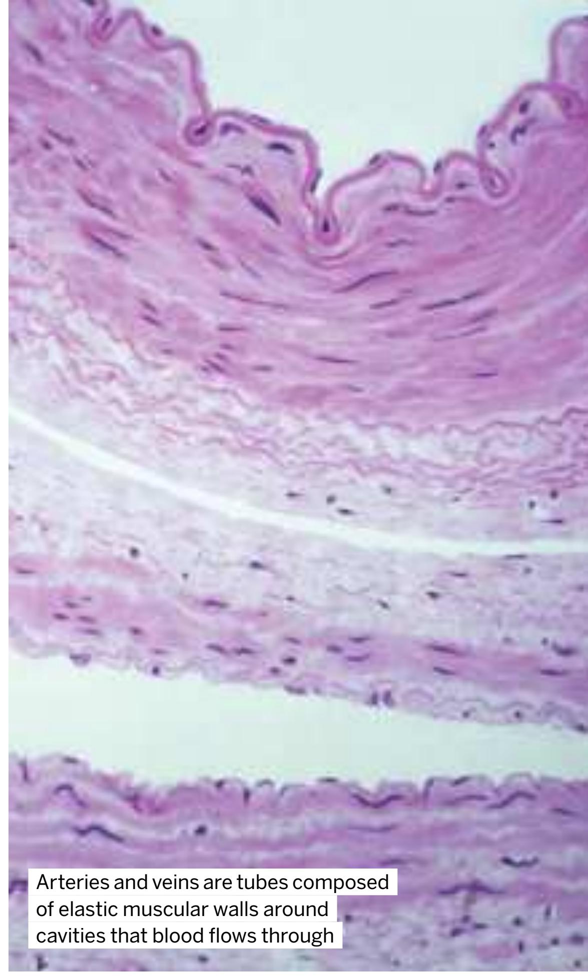
Every cell in the human body requires oxygen to produce energy, but most of our cells cannot access it directly. A single-celled life form interacts directly with its environment, exchanging nutrients and waste products as required. But our ancestors gave up that lifestyle hundreds of millions of years ago when they evolved to become multicellular.

As multicellular life grew more sophisticated, our ancestors' cells became specialised and compartmentalised. Then, many millions of years later, their descendants migrated from the ocean to the land. Gone were the days when even external cells exchanged nutrients with their environment – now our ancestors' cells were encased inside a protective barrier of skin, allowing them to retain their water and maintain consistent internal temperatures. This meant that precious few cells interacted with the environment, and therefore very few cells could access much-needed oxygen and sugars for energy. Fortunately, our species – just like our land-treading ancestors – possesses an interwoven network of tissues and organs dedicated to ensuring our cells acquire the nutrients they need. We call this network the circulatory system.

This vascular network consists of a pump – the heart – and a connected network of blood vessels that carry blood to and from internal tissues. If blood and its component parts are the delivery service, busily dispensing oxygen and collecting waste, then blood vessels are the highways and smaller roads on which they travel. Together with the heart, which provides the pressure that propels blood around the circuit in the body, blood vessels are essential for maintaining the health and functionality of our cells. Our circulatory system is also highly adaptable. When we're at rest and require less energy, heart rate slows. However, when we move about and exercise the heart rate rises.

You can feel the beating heart in action for yourself by placing a finger on the left side of your wrist or by softly placing a finger next to the left side of your windpipe. When you do this, you're feeling your pulse through the radial and carotid arteries respectively. As well as the heart, blood vessels themselves react to environmental changes. When it's cold, for example, blood vessels constrict, helping to reduce heat loss. If you've ever suffered brain freeze, blame your protective blood vessels, which constrict as the cold substance hits the roof of your mouth. The reverse is also true, as blood vessels expand when it's hot to help our bodies shed excess heat. As well as supplying the body with gases and nutrients, our vascular network helps regulate our internal environment, helping to both fuel and protect our cells.

Did you know?
Blood travels around the body in less than 60 seconds

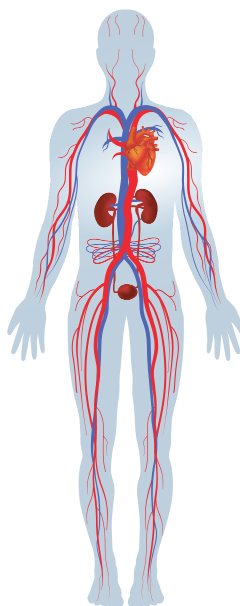

Arteries and veins are tubes composed of elastic muscular walls around cavities that blood flows through

"An interwoven network of tissues and organs dedicated to ensuring our cells acquire nutrients"

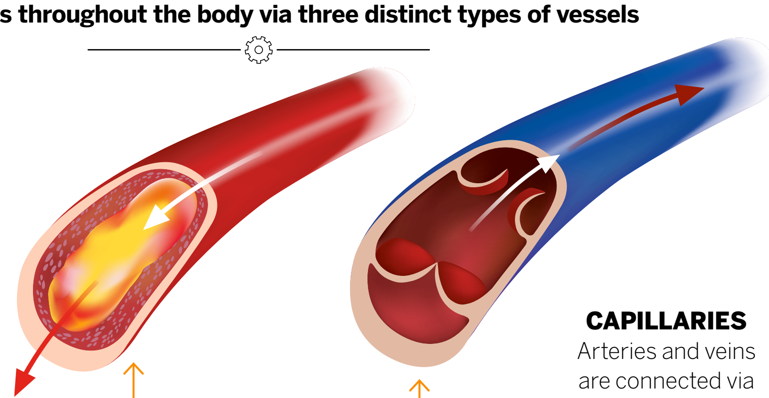

At the heart of all these veins and arteries is our blood-pumping organ

CIRCULATORY COMPONENTS

Blood flows throughout the body via three distinct types of vessels



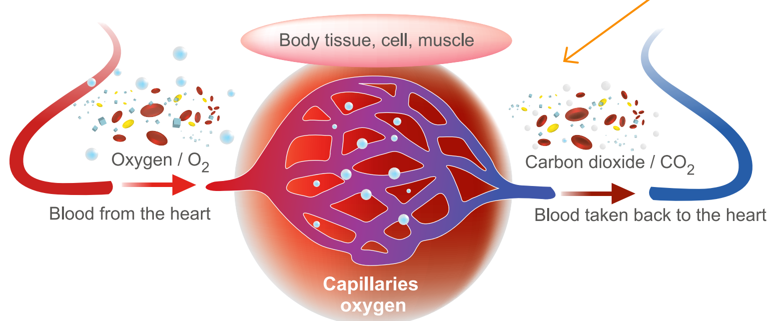
ONE-WAY CIRCUIT
Blood relies on a set of vessels to escort it outwards from the heart and another set to return it, ensuring that blood never needs to flow backwards through the vessels.



ARTERIES
Oxygenated blood flows outwards from the heart through arteries. These vessels have thick walls that allow them to withstand higher blood pressure.

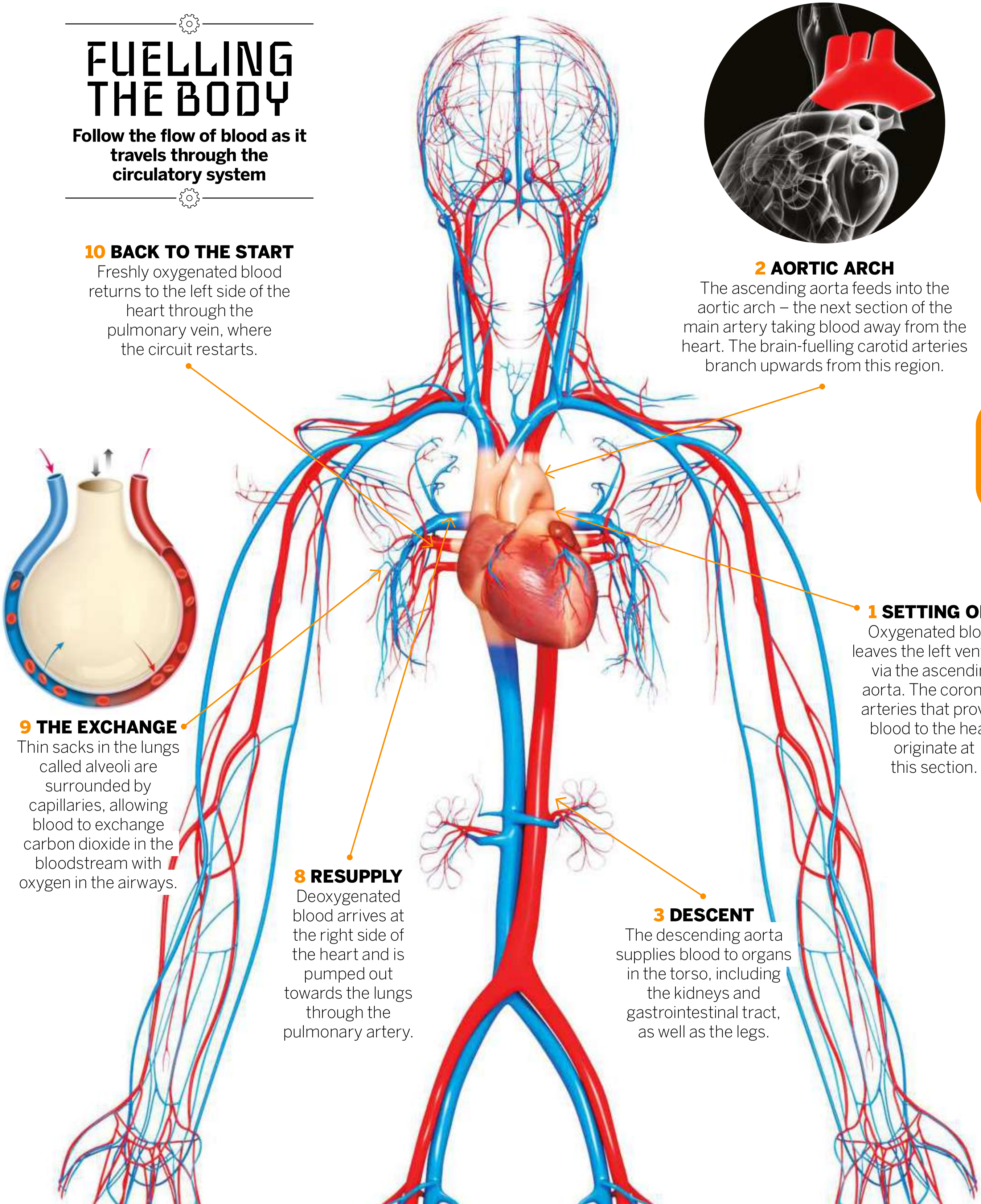
VEINS
Deoxygenated blood returns to the heart through veins. These vessels have thinner walls and use valves to ensure blood only flows in one direction.

CAPILLARIES
Arteries and veins are connected via capillaries. These networks of tiny blood vessels weave through every tissue, where blood releases nutrients and collects waste materials.



FUELLING THE BODY

Follow the flow of blood as it travels through the circulatory system



1 SETTING OFF
Oxygenated blood leaves the left ventricle via the ascending aorta. The coronary arteries that provide blood to the heart originate at this section.

2 AORTIC ARCH
The ascending aorta feeds into the aortic arch – the next section of the main artery taking blood away from the heart. The brain-fuelling carotid arteries branch upwards from this region.

3 DESCENT
The descending aorta supplies blood to organs in the torso, including the kidneys and gastrointestinal tract, as well as the legs.

8 RESUPPLY
Deoxygenated blood arrives at the right side of the heart and is pumped out towards the lungs through the pulmonary artery.

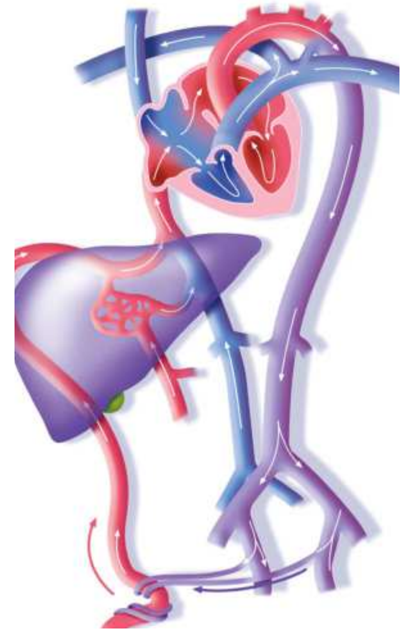
9 THE EXCHANGE
Thin sacks in the lungs called alveoli are surrounded by capillaries, allowing blood to exchange carbon dioxide in the bloodstream with oxygen in the airways.

10 BACK TO THE START
Freshly oxygenated blood returns to the left side of the heart through the pulmonary vein, where the circuit restarts.

CIRCULATION DURING GESTATION

Humans are placental mammals, which means our offspring acquire their nutrients from a placenta during foetal development. Budding embryos swiftly develop a blood supply within the first few weeks of development, but without functioning lungs, kidneys or a gastrointestinal tract, a foetus must rely on its parent for oxygen and nutrients. The maternal blood supply is connected to foetal circulation via the placenta and the umbilical cord, which contains two umbilical arteries and one umbilical vein. The two arteries escort deoxygenated blood from the foetus to the placenta, while the vein carries oxygenated and nutritious blood from the placenta to the foetal heart.

Did you know?
The average adult has about 5.5 litres of blood in their body

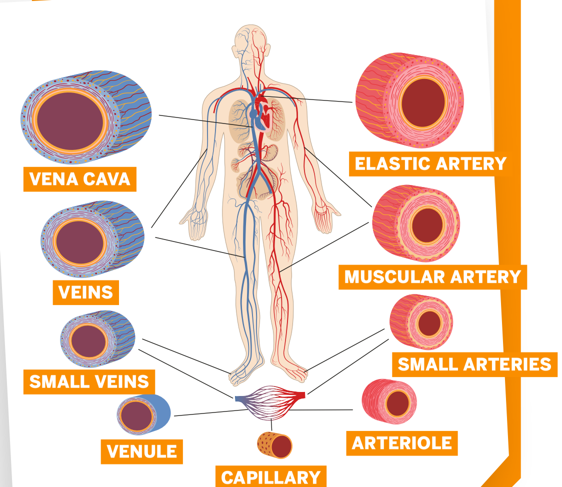


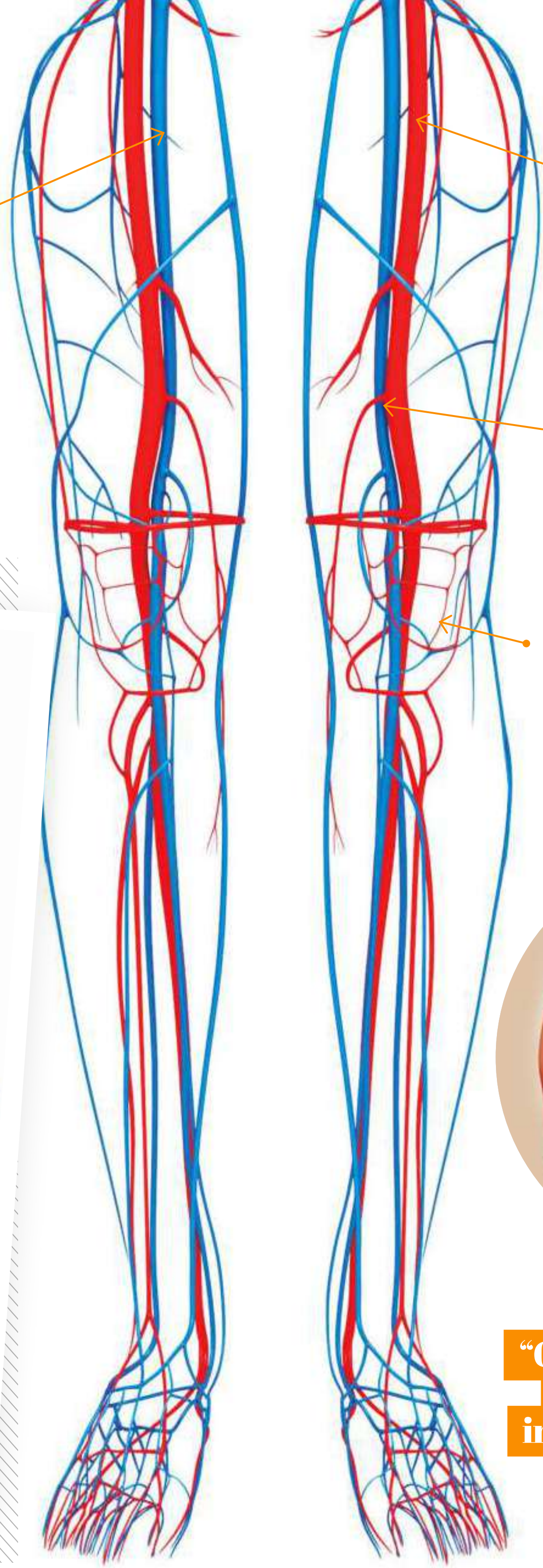
A growing foetus relies on blood exchange with its parent for oxygen and nutrients

TYPES OF BLOOD VESSELS

For blood to efficiently migrate throughout and around the body, it must maintain optimal levels of pressure. Oxygenated blood from the left side of the heart is pumped out at high pressure, so arteries must be able to withstand and maintain this force. They withstand pressure by possessing a thick, muscular wall with an outer, middle and inner layer, and they maintain pressure by possessing a narrow lumen – the space that the blood travels through. Elastic arteries, which are found near the heart muscle, possess more elastic tissue in their middle layer. This helps convert the incremental pulses of pressure from heartbeats into a more constant pressure.

Capillaries are also highly pressurised, but on a much smaller scale. Their lumens are very narrow and their cell walls are only one cell thick. In contrast, veins also possess three layers in their walls, but these are much thinner. But their lumens are much wider, yielding lower pressures.

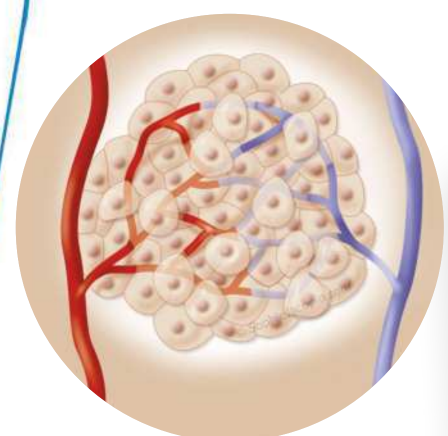




4 INTO THE DEPTHS
The common femoral artery feeds the deep femoral artery that supplies blood to the buttocks, femur and hips, and the superficial femoral artery that supplies the lower leg.

5 BRANCHING PATHS
Blood travels through smaller arteries, into yet smaller arterioles, then into capillaries – the smallest set of blood vessels.

6 NUTRIENTS FOR WASTE
Capillaries are thin enough that oxygen and nutrients can be exchanged for carbon dioxide and waste products between the blood and neighbouring cells. Deoxygenated blood then exits the capillaries into venules.



7 THE RETURN JOURNEY
Smaller venules feed into the major femoral vein, from which blood travels back towards the heart via the inferior vena cava.

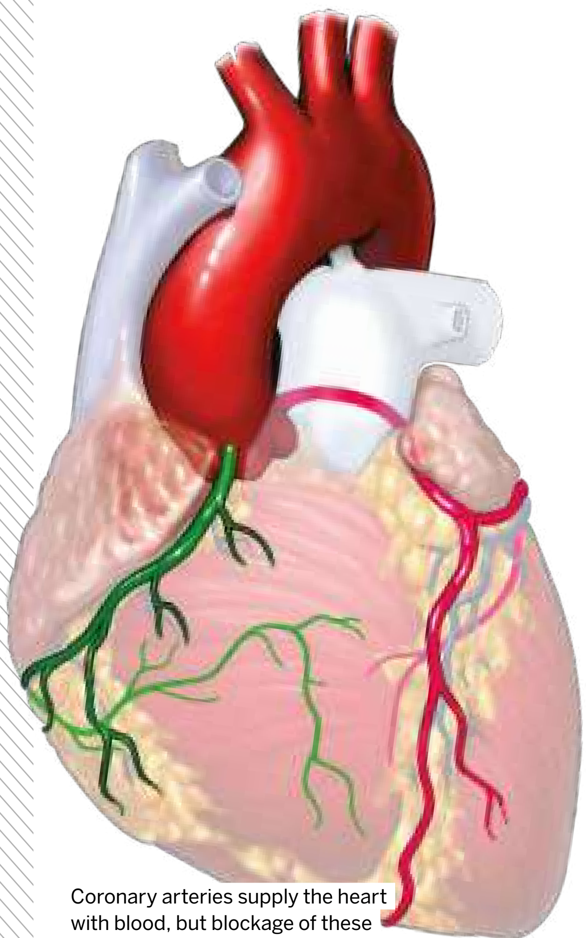
"Our vascular network helps regulate our internal environment"


The abdominal aorta can undergo an aneurysm that causes it to bulge, which can lead to a rupture

SCIENCE

COMMON DISEASES OF BLOOD VESSELS

In the UK, diseases affecting blood vessels are among the biggest killers each year. The cells of our body are so dependent on the oxygen and nutrients supplied by blood that a blockage or rupture in the vascular network can quickly cause catastrophic damage. While some diseases are genetic, many common diseases are caused at least in part by lifestyle choices, such as a poor diet, which results in the bloodstream carrying more harmful compounds than it ideally should. With an increasingly high-fat and sedentary lifestyle, these diseases are growing ever more frequent. Fortunately, however, lifestyle changes and medical innovations are helping to save lives.



Coronary arteries supply the heart with blood, but blockage of these vessels can lead to a heart attack

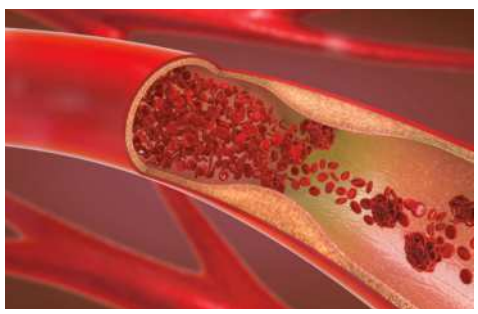
CORONARY ARTERY DISEASE

Just like all other muscles in our body, the heart requires a supply of blood to fuel itself. However, rather than gaining nutrients and oxygen from oxygenated blood pumped in and out of its internal chambers, the heart muscle relies on coronary arteries wrapped around its exterior for its blood supply. Over time, components transported by the blood such as cholesterol can stick to the walls of coronary arteries, initiating blockages that can partially or completely block the blood supply to parts of the heart. This process is known as atherosclerosis and can result in angina, which is chest pain caused by an insufficient blood supply to the heart. If the coronary arteries are fully blocked, however, cell death of part of the heart can occur, causing a heart attack. Coronary artery disease can be treated using bypass graft surgery, where arteries are rerouted to supply the regions of the heart cut off by coronary artery blockages.

Surgery is sometimes necessary to combat blockages and ruptures of the vascular network

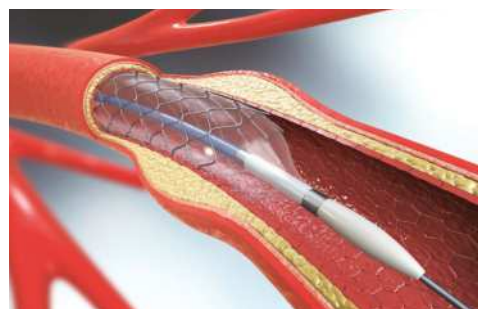
FIXING VESSELS

An angioplasty uses inflated tubes to salvage obstructed arteries



BEFORE

Cholesterol floating in the bloodstream becomes attached to the wall of the artery, drawing fats and causing inflammation. This results in the formation of a plaque which narrows the artery.



AFTER

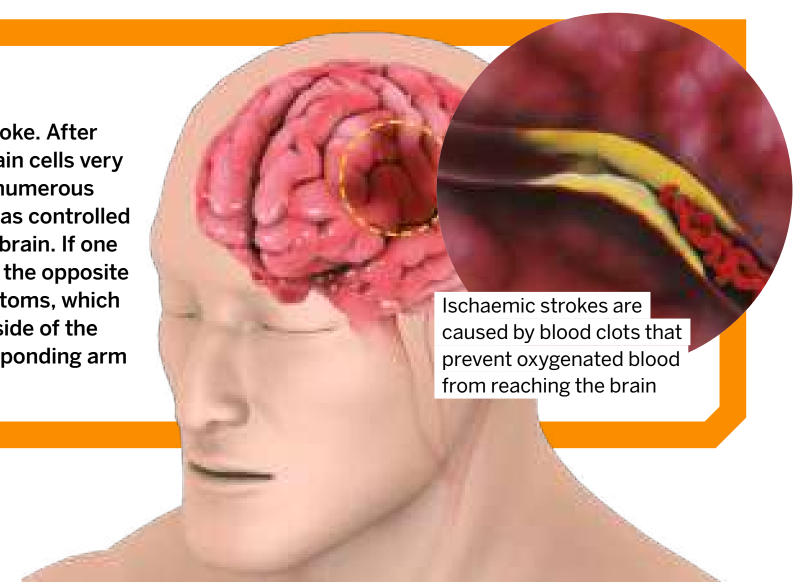
A thin catheter is threaded through the artery towards the plaque buildup. A balloon at the catheter's tip is then inflated, pressing a mesh wire against the plaque, forcing it outwards and widening the artery.

Did you know?

Approximately 85 per cent of strokes involve blockages

STROKE

Atherosclerosis describes the accumulation of plaque on arterial walls. These may originate at various places throughout the body, but can become dislodged and carried elsewhere in the bloodstream. Eventually they can become stuck and cause a blood clot, blocking the artery and preventing blood flow to tissues and organs. If this blood clot occurs in the arteries that feed the brain, it can cause an ischaemic stroke. After being deprived of oxygen, brain cells very swiftly begin to die, causing numerous symptoms relating to the areas controlled by the affected region of the brain. If one side of the brain is damaged, the opposite side of the body shows symptoms, which can include drooping of one side of the face, numbness in the corresponding arm and slurred speech.



Ischaemic strokes are caused by blood clots that prevent oxygenated blood from reaching the brain

DID YOU KNOW? Blood pressure tests measure pressure in mmHg, or millimetres of mercury

PERIPHERAL ARTERY DISEASE

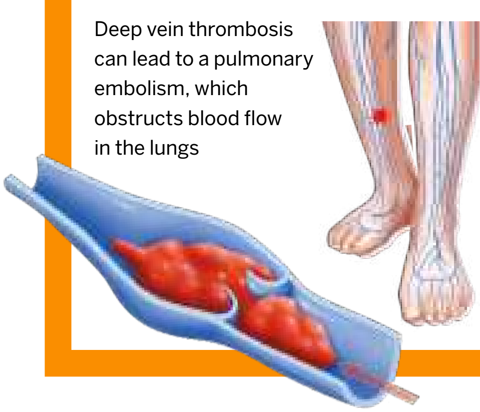
A narrowing or hardening of artery walls can prove fatal when affecting organs such as the heart or brain, but obstructed arteries feeding the peripheral organs can go unnoticed until the disease is at an advanced stage. Depleted blood flow to the legs can cause symptoms such as cramping, an absence of hair and gangrene that occurs following cell death. Individuals living with diabetes are at particular risk of developing peripheral artery disease due to the abundance of glucose in blood plasma. This interferes with other components in the blood, leading to plaque formation. However, a healthy lifestyle involving regular exercise, not smoking and a low-fat, high-fibre diet can help prevent arterial disease for most adults.

When blood flow is cut off from the feet, cells can begin to die, leading to gangrene

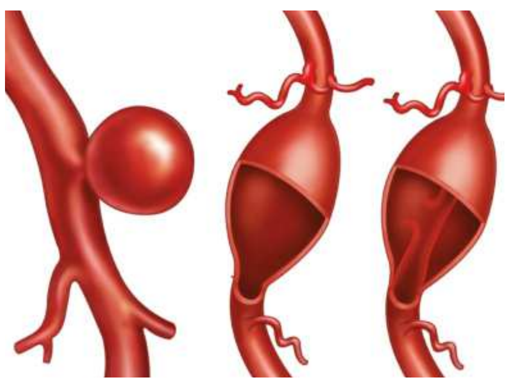
"Diseases affecting blood vessels are among the biggest killers each year"

DEEP VEIN THROMBOSIS

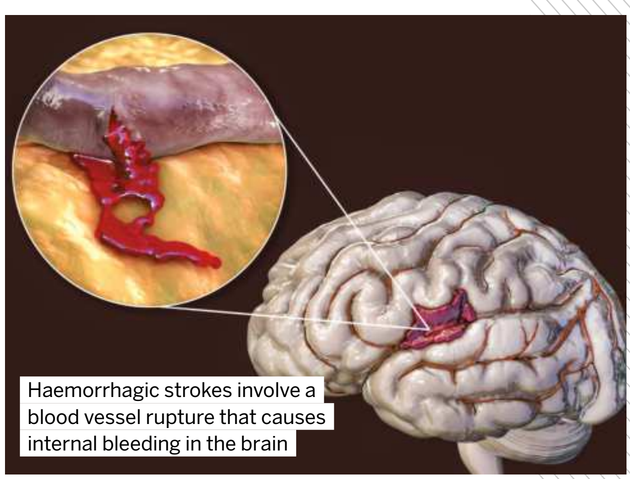
Blood clots can appear rapidly in veins where blood flow is slow and laboured, most common in veins deep in leg muscle. During these cases, such as when a person's legs remain unmoved for long periods, an excess of natural clotting factors in the bloodstream can overstimulate the production of a blood clot. In healthy blood, clots form to prevent bleeding, but during deep vein thrombosis the formed clot can grow to a substantial size – large enough to obstruct blood flow. This can cause pain, swelling and a change in colour of the leg. However, the clot can cause more damage if it travels further through the vascular network into the vessels supplying the lungs, resulting in a pulmonary embolism that can prove fatal.



Deep vein thrombosis can lead to a pulmonary embolism, which obstructs blood flow in the lungs



Blood vessel aneurysms can appear in different forms: secular, with bulges on one side (left); fusiform, with bulges on all sides (centre) or dissect, where blood flows into an internal tear, causing a bulge (right)



Haemorrhagic strokes involve a blood vessel rupture that causes internal bleeding in the brain

8%
Nearly a tenth of your body weight is blood

62,140 MILES
The approximate combined length of blood vessels in the human body

100,000
Estimated deaths from pulmonary embolisms in the US annually

PERITUBULAR CELLS IN THE KIDNEYS CAN DETECT OXYGEN DEFICIENCIES IN THE BLOOD

120/80MMHG
The upper end of healthy blood pressure in an average adult

60 TO 100
Average range of heartbeats per minute in an adult

0.005 MILLIMETRES
The width of your smallest blood vessels are one-tenth that of a hair

THE LIVER RECEIVES THE LARGEST BLOOD SUPPLY WHEN THE BODY IS AT REST

8,000 LITRES
The amount of blood pumped through the vascular network each day

54%
Over half of your blood is found in systemic veins

In general, a young woman will have a higher blood alcohol level than a young man after drinking the same amount of alcohol

WHY WE GET DRUNK

How does alcohol affect the body?

WORDS **AILSA HARVEY**

Whether you're old enough to enjoy the occasional alcoholic drink yourself or have seen some of the bizarre behavioural effects it can have on other people, it's known that drinking alcohol makes people drunk. But what does this mean? What is it in those glasses, bottles or cans that can alter the control people have over their own bodies? The instigator is an ingredient called ethanol, with the chemical formula C_2H_5OH. Ethanol is produced when yeast ferments the sugars in fruit, grains and vegetables. Different alcoholic products are named based on the source of the alcohol. Gin is made from fermented sugar in grains, such as wheat and barley, vodka uses the sugar from potatoes or grain and wine is made from grapes.

While alcohol is produced on an industrial scale for human consumption, plants also produce alcohol naturally in the wild. Neither are humans the only species that consumes alcohol. Many animals eat fermented foods, becoming drunk both accidentally and on purpose. Each species has evolved to handle its alcohol intake differently. For example, pen-tailed treeshrews have the world's highest alcohol tolerance, allowing them to make use of large quantities of fermented plants as a food source. Humans, meanwhile, can risk serious illness and even death if our limits are not carefully considered. From the fun to the harmful, this is how alcohol makes us drunk.

GOING FROM SOBER TO INEBRIATED

Follow alcohol's journey after it enters the body

1 FIRST ENTRY
As soon as alcohol enters the mouth, some of it enters the bloodstream via blood vessels in the mouth and tongue.

2 INTO THE STOMACH
About 20 per cent of alcohol enters the bloodstream in the stomach. This is a slower process if the stomach is full of food.

3 FINAL ABSORPTION
Any remaining alcohol is absorbed into the bloodstream in the small intestine.

4 BLOODSTREAM
Alcohol travels through your body quickly once it reaches the bloodstream. It can also widen blood vessels, causing body temperature changes.

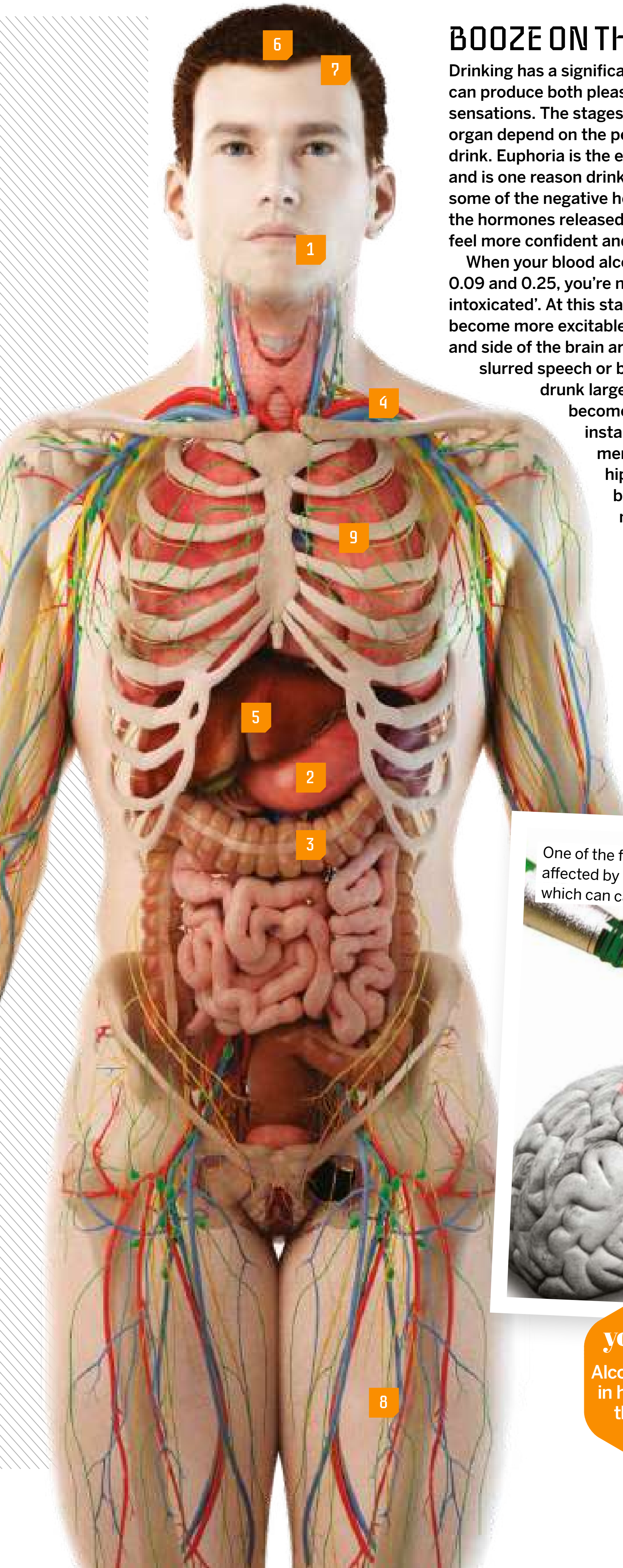
5 BREAKING DOWN
When the alcohol in the blood reaches the liver, the organ works to break down alcohol into carbon dioxide and water. The liver breaks down one unit of alcohol per hour.

6 EFFECT ON THE BRAIN
Alcohol typically reaches the brain within five minutes and begins to make you feel drunk within ten minutes.

7 FEELING GOOD
The hormones dopamine and serotonin are released in the brain, often making drunk people feel happy.

8 SLOWING DOWN
When a high volume of alcohol is consumed, the central nervous system's function is slowed, causing loss of coordination and dizziness.

9 BOOZY BREATH
About eight per cent of alcohol evaporates from the blood to the lungs. As it's transferred into the breath, alcohol can be detected by a breathalyser.

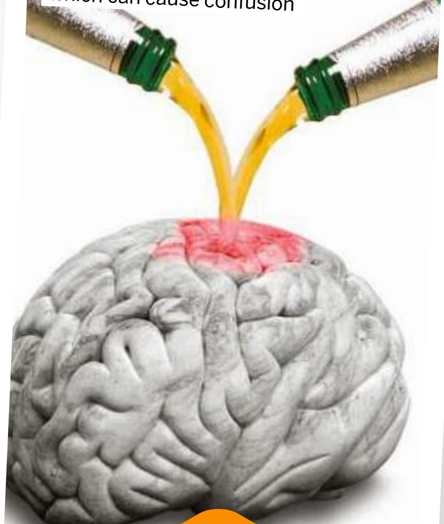


BOOZE ON THE BRAIN

Drinking has a significant impact on the brain and can produce both pleasant and unpleasant sensations. The stages of alcohol's impact on this organ depend on the person and how much they drink. Euphoria is the early stage of feeling drunk, and is one reason drinking is so popular despite some of the negative health impacts. At this stage the hormones released in the brain might make you feel more confident and relaxed.

When your blood alcohol level reaches between 0.09 and 0.25, you're now classed as 'legally intoxicated'. At this stage, a drunk person might become more excitable. The lobes at the front, back and side of the brain are affected and can cause slurred speech or blurred vision. If someone has drunk large volumes of alcohol they can become disorientated, and in some instances lose their short-term memory. This is because the hippocampus – the area of the brain responsible for making new memories – is hindered. The nerves in this area of the brain are slowed down by alcohol. The stages beyond this become more serious and worrying, as the brain will eventually fail to keep vital organs functioning. When a person's blood alcohol level reaches between 0.25 and 0.35, the body is at risk of alcohol poisoning, coma and death.

One of the first areas of the brain to be affected by alcohol is the cerebral cortex, which can cause confusion



Did you know?

Alcohol can remain in hair follicles for three months

ANIMALS AND ALCOHOL

ELEPHANTS

Elephants don't have the same mutation in the gene ADH7 as humans and many other mammals. This means that despite their size, they can get drunk on relatively small amounts of fermented fruit compared to their body size.

BATS

Egyptian fruit bats like ripe fruit, such as figs and dates. But when they eat foods with over one per cent ethanol, they can become tipsy. Bats have mastered flying drunk. One study showed that New World bats can use echolocation to navigate just as well when drunk.

MONKEYS

Vervet monkeys developed a taste for alcohol after discovering fermented sugar cane. Research discovered that the teenage monkeys got drunk more than adults and one in five monkeys preferred alcoholic water over sugar water.

BEES

Honeybees can become intoxicated after drinking fermented limes and tree sap. In many instances, bees have failed to make their way back to their hives after sipping ethanol. Sometimes those that do return aren't allowed back in.

BIRDS

Berries ferment in winter, which can make the birds that feed on them drunk. The bohemian waxwing is one such species. Most become tipsy but remain in control, but some eat too many alcohol-filled berries can't fly straight.

SHAMPOO SCIENCE

What chemical processes occur within the foaming lather of shampoo?

WORDS AILSA HARVEY

Leaving hair unwashed for multiple days can cause it to feel heavy and greasy. This is because the scalp is continuously producing a natural oil called sebum. Without this sebum shield, the proteins within our hair would become damaged more easily. When there is a build-up of this oil and our hair is in need of a wash, water alone can't remove it very effectively.

Sebum largely resists mixing with water, especially if the water is cool, but when the water combines with shampoo it targets the oil. Molecules in shampoo called surfactants work to produce a frothy lather. They have two polar ends – one being hydrophobic (repelled by the water) and one being hydrophilic (attracted to the water). When rubbed into hair with both water and oil, the grease and dirt is carried off hair and down the drain.

DIFFERENT QUALITIES FOR ALL HAIR TYPES

Anti-frizz shampoo often contains added silicones to make hair smoother. To achieve this, silicones act as a barrier against moisture. This stops hair from drying out, as well as preventing humid weather contributing to frizziness. Shampoos with more silicones aren't recommended for fine hair, as the weight they add can cause strands to break. Medical products like anti-dandruff shampoo contain ingredients to soothe discomfort experienced on the scalp and target more specific scalp issues. For dandruff sufferers, pyrithione zinc can be added to kill the *Malassezia* yeast that causes the condition.

Hairdressers use different shampoo types based on a customer's needs

DID YOU KNOW? Before shampoo, vegetable starch or wood ash could be rubbed into hair to absorb grease

WHAT DO YOU PUT ON YOUR HAIR?

These are the basic ingredients of shampoo

10-20% SURFACTANTS

These ingredients lower the surface tension between oils and water, allowing the shampoo to bind with grease and remove it during washing.

0.3-0.5% FRAGRANCE

Multiple ingredients can be added to create the smell of your shampoo. These may include natural chemicals such as menthol or synthetically produced fragrances such as jasmine-smelling amyl cinnamal.

1% PRESERVATIVES

Ingredients such as sodium benzoate, potassium sorbate or sorbic acid prevent bacteria from growing in the bottle.

2% CONDITIONERS

To retain natural oils in the hair, conditioning substances such as glycerin attract any surrounding moisture.

2% THICKENERS

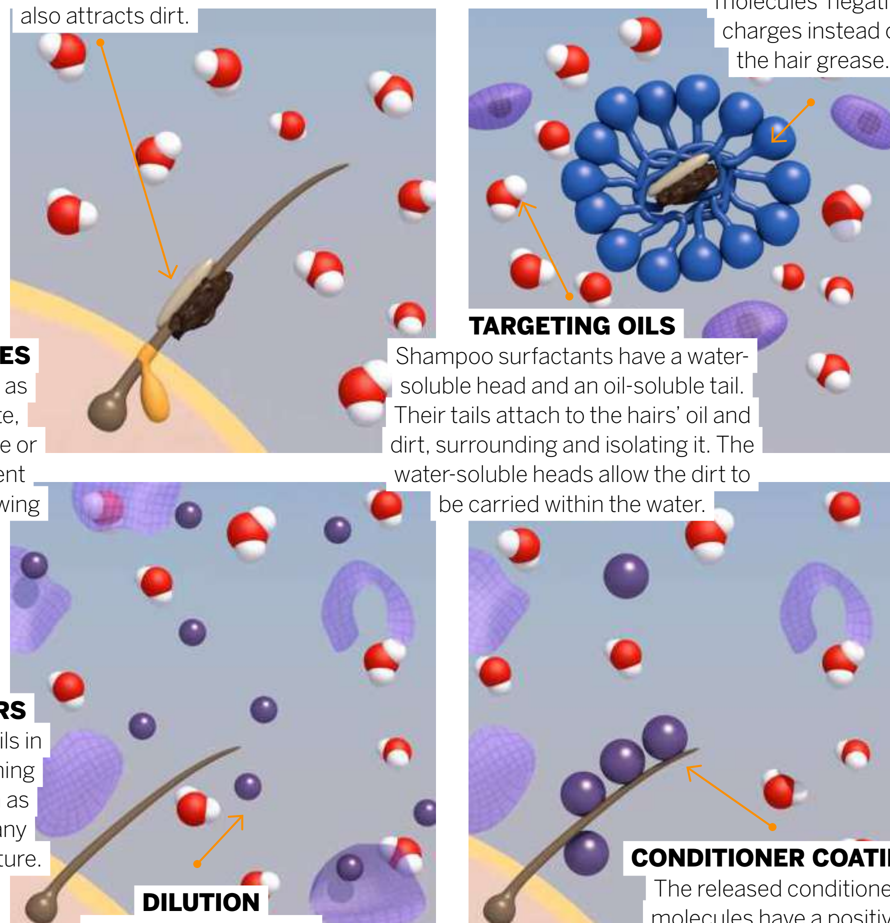
Alcohols, carnauba wax and xanthan gum are among common shampoo thickeners. These help create the shampoo's flow and consistency.

75-80% CARRYING AGENTS

The majority of shampoo's content is water. This helps to activate the other ingredients by binding cleaning agents to oil.

THE CLEANING PROCESS

Take a close-up look at the chemistry of a hair wash



OILY BUILD-UP

The scalp produces a waxy substance called sebum; this stops hair from drying out but also attracts dirt.

TARGETING OILS

Shampoo surfactants have a water-soluble head and an oil-soluble tail. Their tails attach to the hairs' oil and dirt, surrounding and isolating it. The water-soluble heads allow the dirt to be carried within the water.

ISOLATED CONDITIONERS

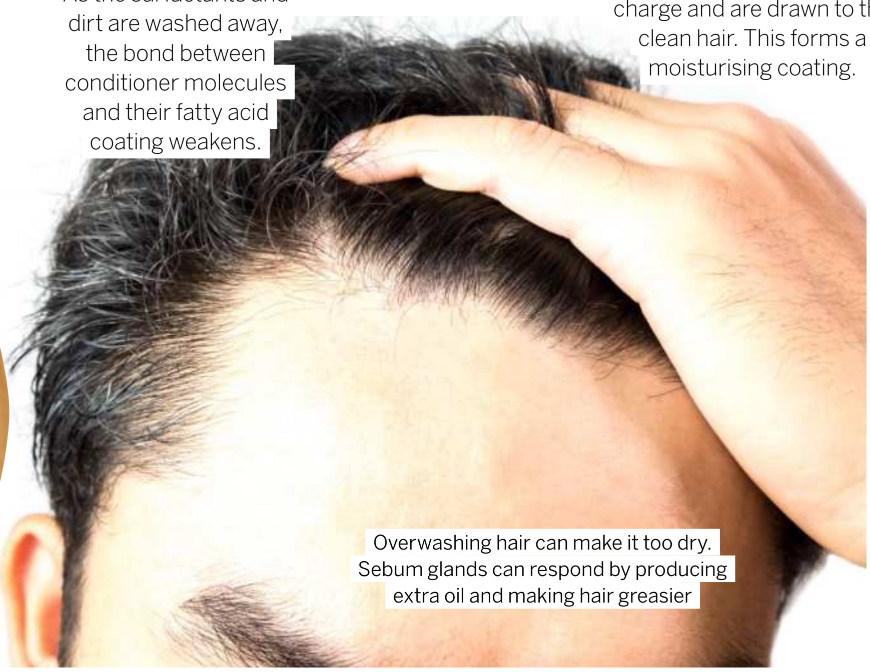
Conditioner molecules are positively charged, so they attract a fatty acid coating. This stops them from binding with the shampoo molecules' negative charges instead of the hair grease.

DILUTION

As the surfactants and dirt are washed away, the bond between conditioner molecules and their fatty acid coating weakens.

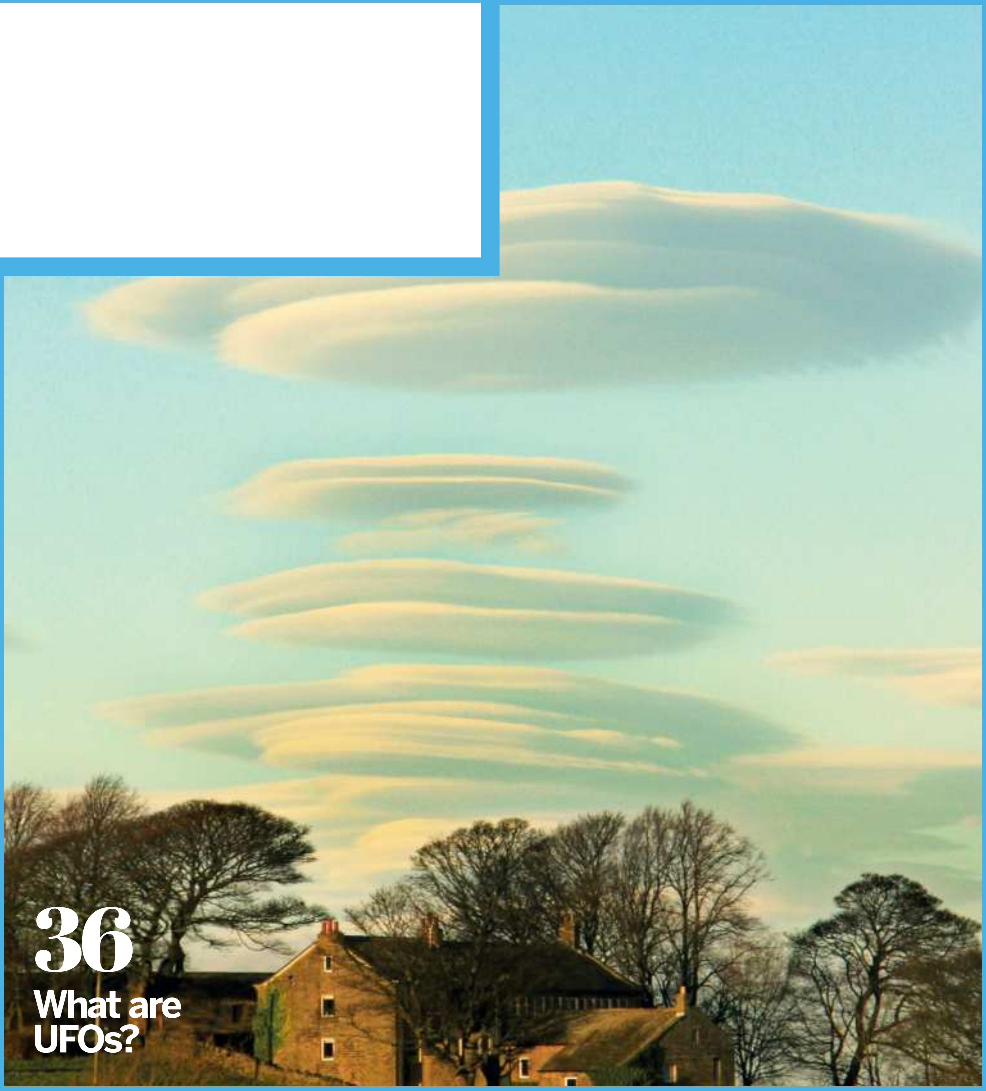
CONDITIONER COATING

The released conditioner molecules have a positive charge and are drawn to the clean hair. This forms a moisturising coating.



Overwashing hair can make it too dry. Sebum glands can respond by producing extra oil and making hair greasier

SPACE



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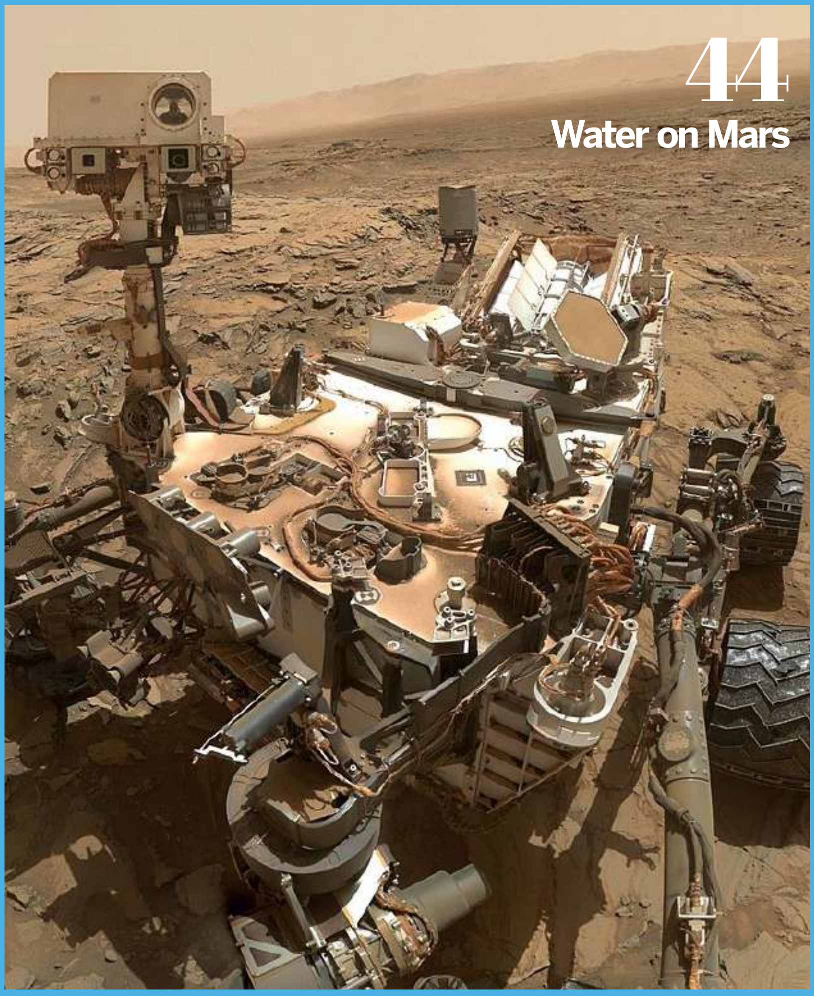
What are UFOs?



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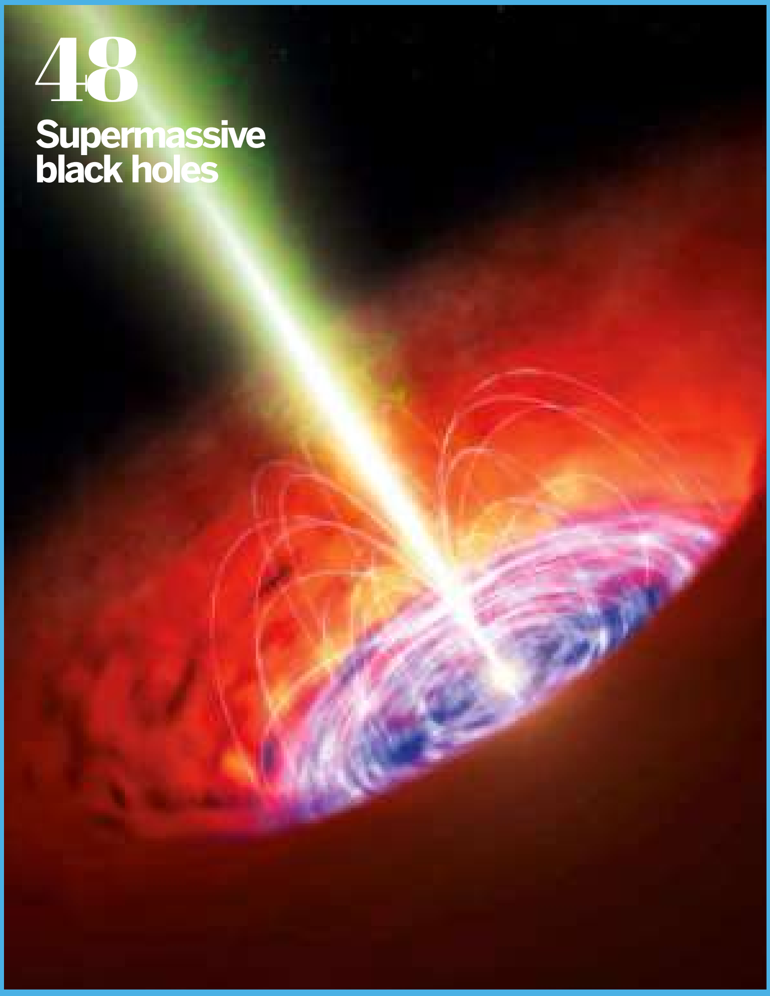
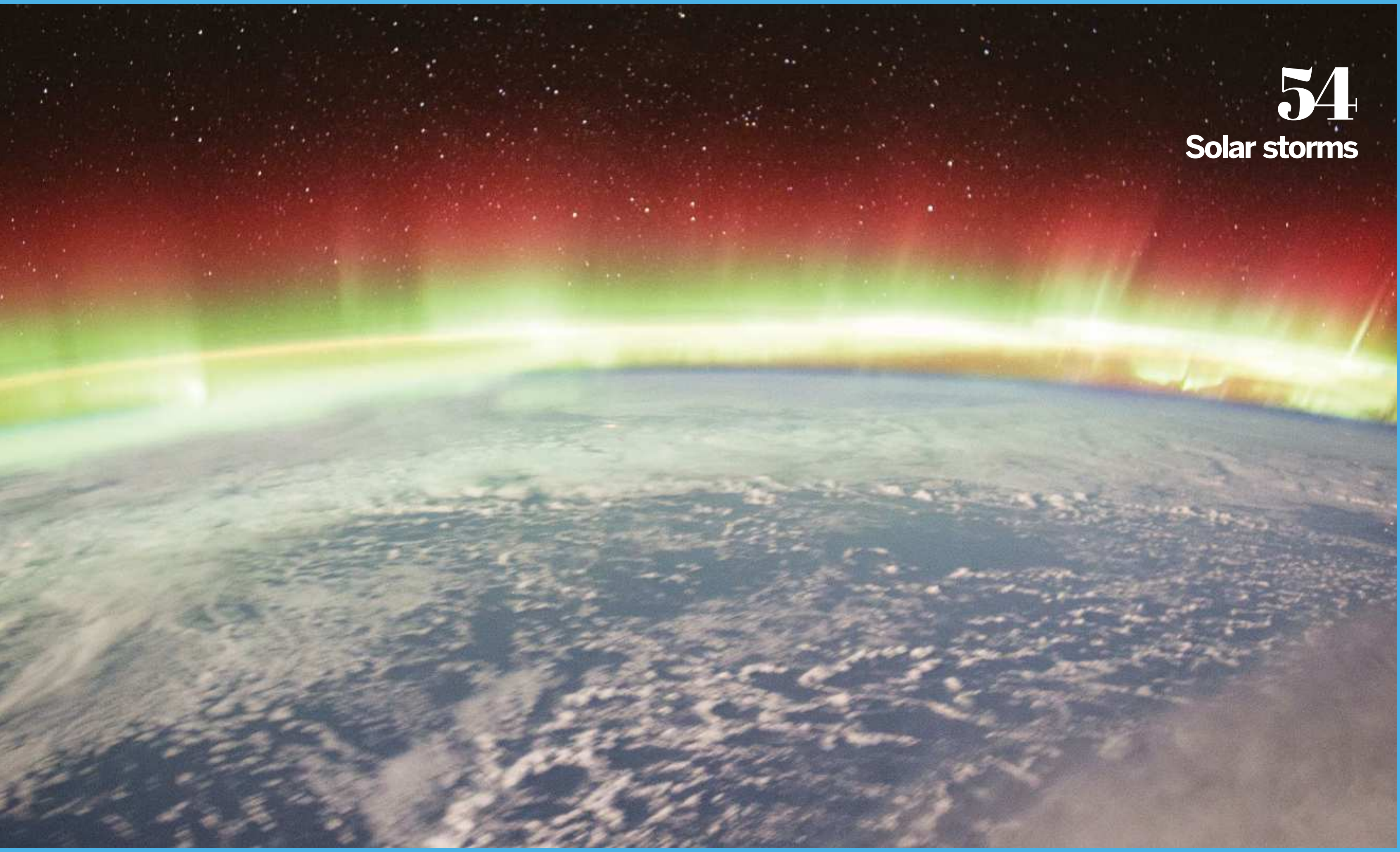
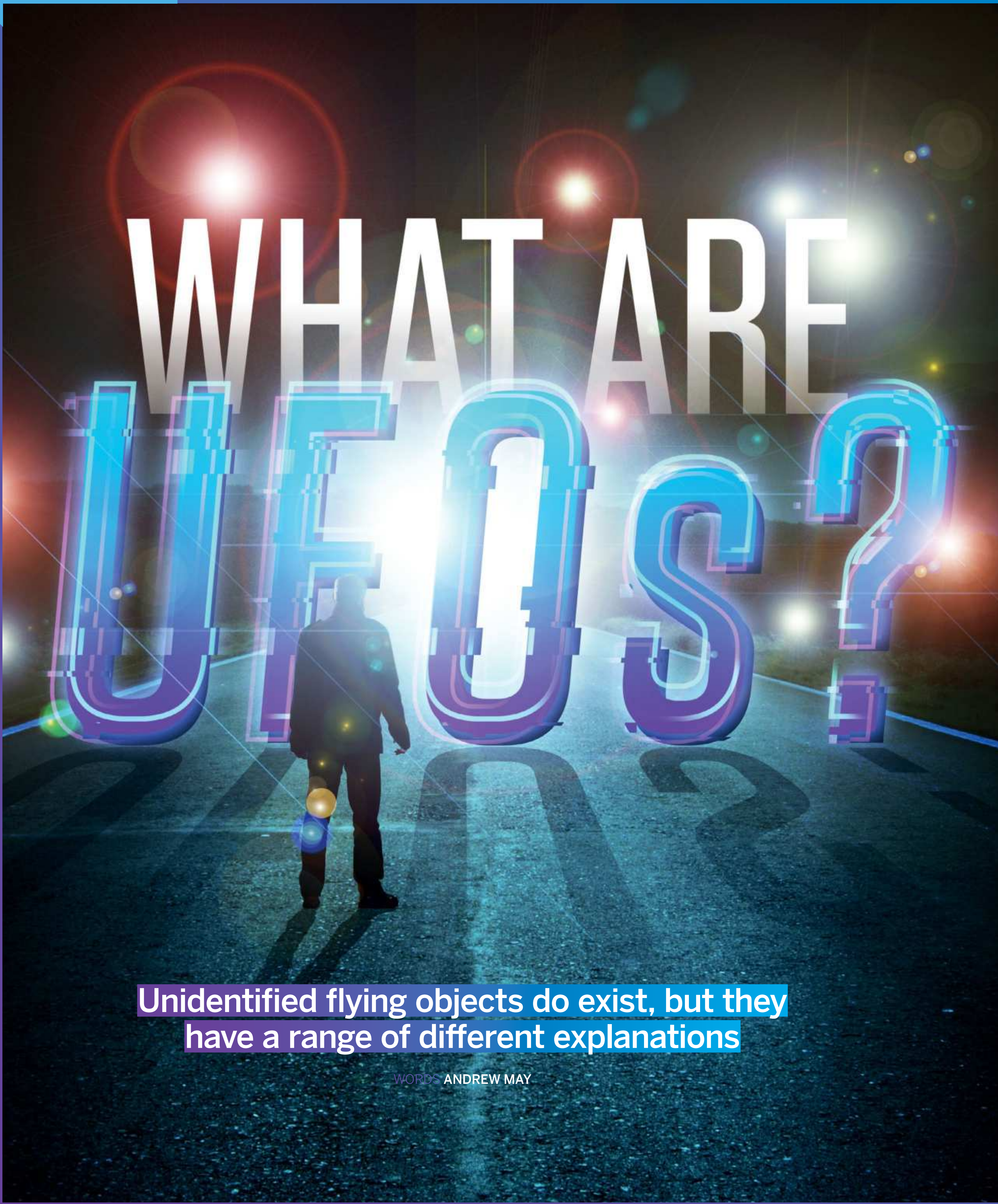
Water on Mars



48
Supermassive black holes


54
Solar storms


58
Can we create artificial gravity?



WHAT ARE UFOs?

Unidentified flying objects do exist, but they have a range of different explanations

WORDS ANDREW MAY

There have been sightings of strange things in the sky since ancient times, but it was only in the middle of the 20th century they acquired the name 'unidentified flying object', or UFO. During the 1940s and 1950s, there was a huge surge in sightings around the world, often described as disc-shaped craft or 'flying saucers'. The timing of this first great UFO wave was significant, coming at a period of widespread public paranoia caused by the nuclear arms race. The most common theory in the early days was that UFOs were advanced military aircraft that had been developed in total secrecy.

Within a few years public perceptions changed, thanks in part to Hollywood. Suddenly UFOs were no longer assumed to originate on Earth, but from another planet. Since then, the situation has been complicated by other alleged evidence for extraterrestrial visitation, from rumours that governments are concealing information about their dealings with UFO occupants to apparent memories of alien abduction recalled under hypnosis. Although these cases have little or no direct connection to strange objects seen in the sky, the term UFO still tends to be applied to them. Last year, for example, a UK newspaper carried the headline 'UFO hunter spots alien lizard on Mars', even though no flying object was involved.

The fact is that the terminology has become hopelessly confused. To some people, particularly in official circles, 'unidentified flying object' means just that: an airborne object that hasn't been identified. To many ordinary people, however, UFO means 'alien spacecraft'. For this reason, the US military has started using the term UAP, for unidentified aerial phenomena, to avoid appearing to talk about extraterrestrials every time they say they've seen something they can't explain. And UAP has another advantage, because UFOs may not always be literal 'flying objects'. As you'll see, some may be mirages, unusual weather effects or even astronomical bodies. Therefore 'aerial phenomena' is a much more appropriate term in these cases.

UFO and UAP do have one letter in common, and that's U, for unidentified. But it's important not to read too much into this. It doesn't automatically mean that what's been spotted came from another planet, or defies the known laws of physics. In the case of a photograph or video, for example, the resolution simply may not be good enough to work out what it shows.

With a fleeting eyewitness report, even by a trained observer like a pilot or police officer, if they had no firm idea of the size or distance of the object, it might have been anything from a person's drone to an alien starship. And electronic systems such as radar are designed to pick up particular types of known objects, so anything falling outside the expected parameters is likely to be classed as 'unidentified'. A proportion of UFO reports still remain unexplained – but not necessarily extraterrestrial – even after careful investigation.

The majority of sightings can eventually be ascribed to known causes – anything from top-secret spy planes to obscure atmospheric phenomena. We'll take a look at some of these 'real-world UFOs' here, as well as questioning one of the people behind the public release of half a century's worth of Ministry of Defence (MoD) UFO files.

Above: Cloud phenomena are responsible for some sightings

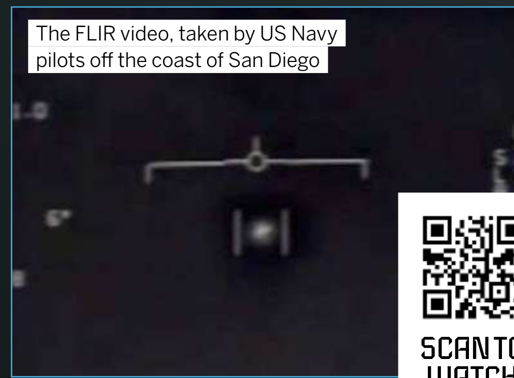
Above inset: In common usage, UFO means alien spaceship, but there are many other explanations

THE PENTAGON UFO VIDEOS

The idea that some UFO sightings might represent genuinely unknown phenomena was given a boost in 2020 when the Pentagon – the US defence headquarters – released three videos staff admitted couldn't be explained. The low-resolution, black-and-white videos show the instrument displays inside US Navy fighter jets, recorded during encounters that baffled flight crews at the time. The first video, entitled 'FLIR' – for Forward-Looking Infrared, a reference to the equipment used to capture the video – dates from 2004, while two others, called 'GIMBAL' and 'GOFAST', come from 2015. The latter are more dramatic, with the 'UFO' apparently in rapid motion and the crew's surprised reactions audible in the background.

Despite the Pentagon's inability to explain the videos, numerous theories have been put forward by the public, ranging from optical illusions and instrument malfunctions to unusual atmospheric phenomena and – of course – alien spacecraft.


A still from a US Navy video, dating from 2019, appears to show a triangular UFO


The FLIR video, taken by US Navy pilots off the coast of San Diego

SCAN TO WATCH


The GIMBAL video, showing an encounter off the US east coast


This video, called GOFAST, is from the same encounter as GIMBAL

"The Pentagon released three videos staff admitted couldn't be explained"


The bright planet Venus is frequently mistaken for a UFO

Did you know? Some UFO sightings have been exposed as hoaxes

PARALLAX ILLUSION

If you walk past a stationary object, it appears to move relative to the background. This effect is called parallax, and our brains are so used to it we don't notice when everyday objects are involved. But if there aren't any familiar visual cues, it really can seem as though a stationary object is in motion. Some believe this is what we're seeing in the GOFAST video. The idea is that the object is nowhere near the sea's surface, but much closer to the aircraft taking the video. Even if the object was almost stationary, it would appear to whiz over the sea at the same speed as the aircraft itself.

How parallax makes stationary objects appear to move against a distant background

SCAN TO WATCH

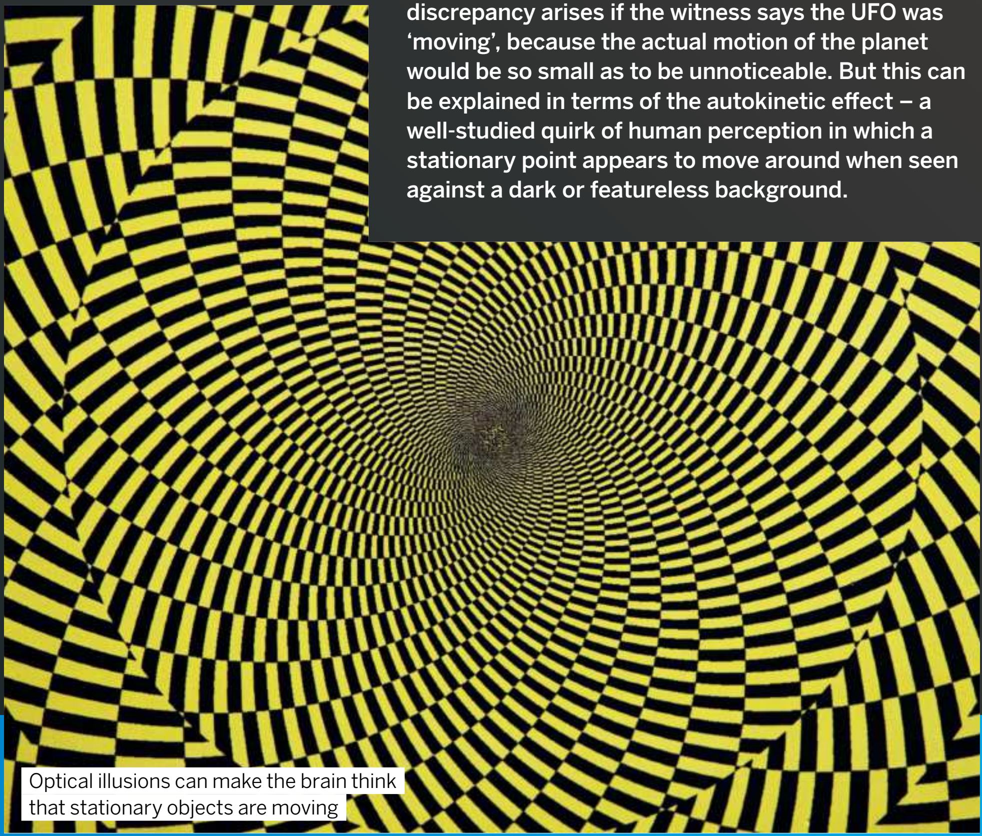
GRAVITY-DEFYING MIRAGES

In certain weather, particularly over the sea or flat terrain, it's possible to see distant objects 'hovering' in midair. Sometimes it's obvious that what you're seeing is a building or a ship, but other times it can look like a UFO. But this has a perfectly rational explanation in terms of optics. It all comes down to the fact that light doesn't always travel in straight lines. In medieval times people thought mirages were created by supernatural means, dubbing them Fata Morgana after a mythical sorceress.

This looks like a hovering spaceship, but it's a Fata Morgana mirage

THE AUTOKINETIC EFFECT

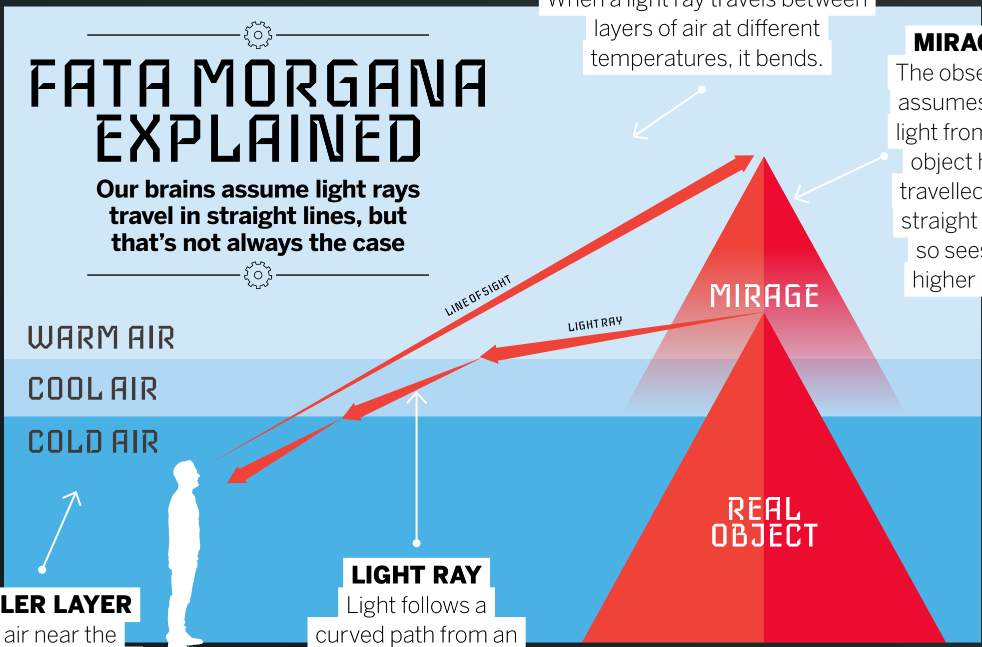
Over the years, a large number of UFO sightings have been found to be misidentifications of the planet Venus. In these cases, the location of the object in the sky, as described by the witness, exactly matched the known position of Venus at that time. An apparent discrepancy arises if the witness says the UFO was 'moving', because the actual motion of the planet would be so small as to be unnoticeable. But this can be explained in terms of the autokinetic effect – a well-studied quirk of human perception in which a stationary point appears to move around when seen against a dark or featureless background.



Optical illusions can make the brain think that stationary objects are moving

FATA MORGANA EXPLAINED

Our brains assume light rays travel in straight lines, but that's not always the case



WARMER LAYER When a light ray travels between layers of air at different temperatures, it bends.

MIRAGE The observer assumes the light from the object has travelled in a straight line, so sees it higher up.

COOLER LAYER The air near the ground is at a lower temperature than the air higher up.

LIGHT RAY Light follows a curved path from an object in the warm layer to an observer in the cool layer.

TOP-SECRET AIRCRAFT

The B-2 stealth bomber looks like alien tech from certain angles

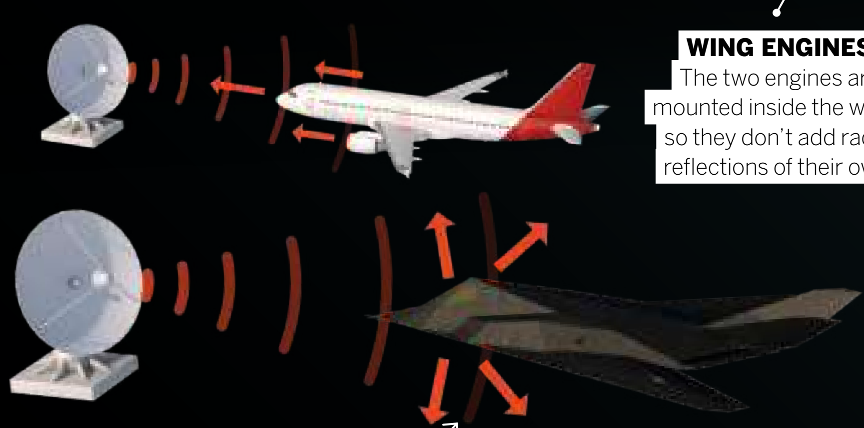
Many UFOs aren't 'flying objects' at all, but planets, mirages or unusual atmospheric phenomena. On the other hand, some are exactly what they appear to be – ultra-futuristic flying machines – except they originate here on Earth, not in outer space. The CIA estimates that more than half of all UFOs reported in the US during the 1950s and 1960s were the nation's own spy planes. The very existence of these aircraft was a carefully guarded state secret, and the military much preferred the public to speculate about aliens than to uncover the true facts. A new twist was added in the 1970s with the advent of stealth aircraft such as the F-117, and later the B-2. During their development and initial deployment, these were every bit as secret as the earlier spy planes, while the requirement to disrupt incoming radar signals made them the most oddly shaped aircraft in the sky.

Did you know?
During WWII, allied pilots referred to UFOs as foo fighters

NORTHROP GRUMMAN B-2

The B-2's weird appearance doesn't mean it's from another planet... it's all about stealth

WING ENGINES
The two engines are mounted inside the wings so they don't add radar reflections of their own.



RADAR SCATTERING
Rather than reflecting radar waves back the way they came, the B-2 is shaped so

Seen nose-on, the Lockheed Martin F-117 looks like a classic UFO

LOCKHEED F-117 NIGHTHAWK 1981

Designed primarily for stealth, the F-117 was developed – and initially operated – in total secrecy. Its existence was only revealed to the public in 1988, five years after it entered service with the US Air Force. The combination of secrecy and a strikingly unconventional appearance were guaranteed to produce UFO reports.

DID YOU KNOW? The F-117 and several other futuristic aircraft originated at Lockheed's secret 'Skunk Works'

COOL EXHAUST
The engine nozzles are designed to reduce the exhaust temperature in a way that minimises infrared emissions.

RADAR-ABSORBENT COATING
To further reduce radar returns, the aircraft is covered in specially absorbent material.

ROUNDED SHAPE
None of the B-2's surfaces are completely flat, because these would act like a reflective mirror to radar.

WING-BODY BLEND
The B-2 is virtually a flying wing, with the fuselage blended into it, to minimise its visibility to radar.

A SpaceX launch in 2017 put on a spectacular show that triggered numerous UFO reports

Even a hobbyist's drone can be mistaken for a UFO, especially if seen at night

Only one V-173 was built

VOUGHT V-173 1942 'FLYING PANCAKE'

This weird experimental aircraft was built for the US Navy at the start of World War II. A classic 'flying saucer' shape with an almost-circular disc-shaped wing, it underwent almost 200 test flights in the Connecticut area, prompting numerous UFO reports from locals.

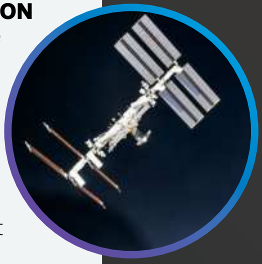
The Ho 229 was the first flying wing powered by jet engines

HORTEN HO 229 FLYING WING 1944

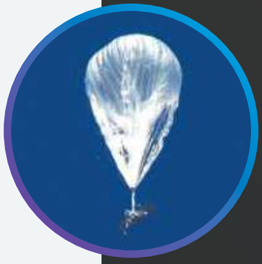
An aircraft way ahead of its time, this jet-powered flying wing superficially resembles the Northrop Grumman B-2 built half a century later. The Ho 229 was built by Nazi Germany for a last-ditch offensive against the Allies, but the war ended before it could enter service.

IDENTIFIED FLYING OBJECTS

INTERNATIONAL SPACE STATION
If it catches the Sun as it passes overhead just after sunset or before sunrise, the fast ISS can be a puzzling sight to anyone not expecting it.

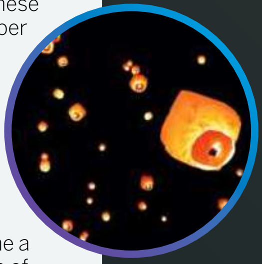


WEATHER BALLOONS
Around the world, thousands of high-altitude balloons are launched every day to gather data for weather forecasters. Their appearance and behaviour can seem mysterious to anyone unfamiliar with them.

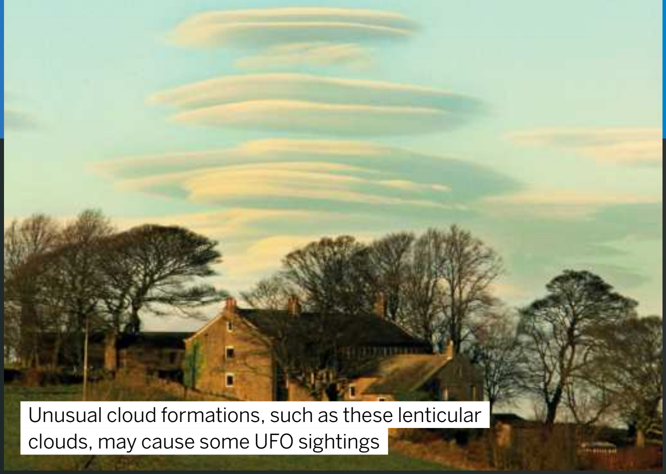


SATELLITE LAUNCHES
With the new generation of broadband satellites, such as Starlink, being launched in batches, the tightly clustered satellites seen just after launch are often mistaken for UFOs.

SKY LANTERNS
The craze for these celebratory paper balloons, illuminated by candles and launched en masse, began in China, but is now worldwide. They've become a common cause of UFO sightings.



ATMOSPHERIC PHENOMENA



Unusual cloud formations, such as these lenticular clouds, may cause some UFO sightings

Earth's atmosphere is a dynamic, constantly changing environment, and some of the more spectacular effects that occur in it can look like UFOs to the uninitiated. These include the unusual weather phenomena described in the graphics here, such as ball lightning, fallstreak holes and lenticular clouds. The latter in particular are a perennial cause of UFO sightings due to their highly symmetrical and structured appearance.

In a single month in 2015, the *Houston Chronicle* reported dozens of these false alarms, quoting one excited Twitter user as saying: "The sky over Texas appears to be filled with UFOs!"

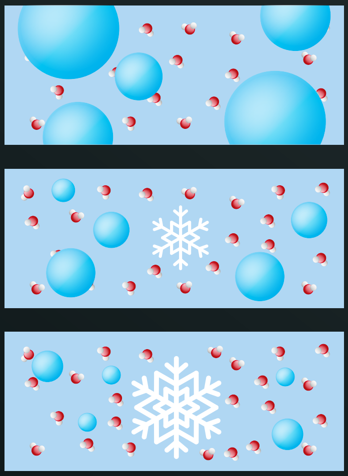
Meteors are another natural phenomenon that can be mistaken for UFOs. These really do come from space, although they're just dust or small pieces of rock rather than alien spacecraft. They produce a glowing trail as they enter the atmosphere, and larger ones may explode on the way down – sometimes audibly – creating a spectacular light show that is almost guaranteed to generate UFO reports. Similar effects can be produced by human-made space junk, such as derelict satellites, as they re-enter the atmosphere.

Did you know?
A hundred tonnes worth of meteors hit Earth every day

> "There are almost as many explanations as there are sightings"

FALLSTREAK CLOUDS

This odd phenomenon causes a circular hole to appear in an otherwise normal cloud layer



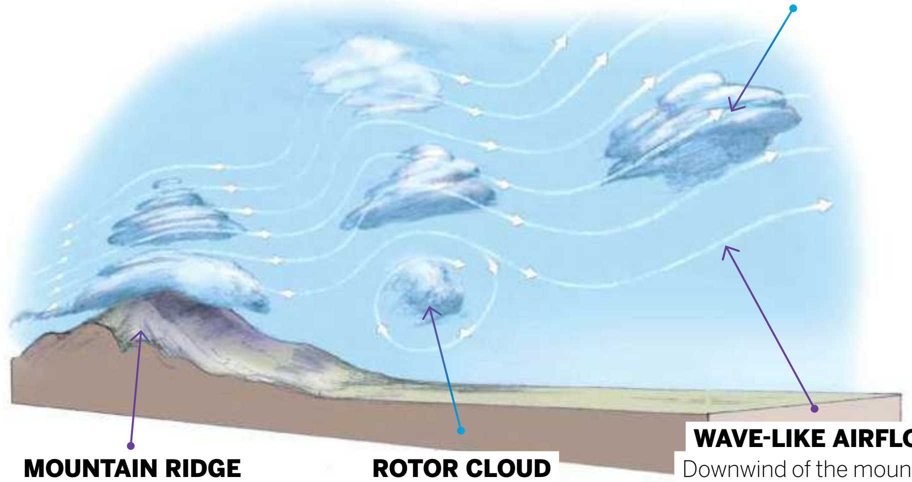
SUPERCOOLED CLOUD
Temperatures are below freezing, but the water droplets remain liquid due to a lack of ice nucleation particles.

CLOUD FREEZES
When ice crystals start to form, they set off a domino effect in which more and more water freezes.

A HOLE IS CREATED
When the ice crystals are big enough, they begin to fall as snow, leaving a big hole in the cloud.

LENTICULAR CLOUDS

These strikingly dramatic clouds can often look like giant flying saucers



LENTICULAR CLOUDS
The characteristic saucer-shaped clouds form at the peak of the standing wave, constantly replenished by incoming moist air.

MOUNTAIN RIDGE
A current of moist air is forced up and over a high ridge.

ROTOR CLOUD
Sometimes a rotating cylindrical cloud can form underneath the lenticular cloud.

WAVE-LIKE AIRFLOW
Downwind of the mountain, the airflow forms a 'standing wave' pattern of crests and troughs.

BALL LIGHTNING

Reports of ball lightning go back centuries, yet it remains a mystery to science. Although it's associated with thunderstorms, it differs from a normal lightning flash in lasting several seconds. Also, as the name suggests, it takes the form of a small sphere. Despite the consistency of eyewitness accounts, unambiguous photographs are scarce, and numerous scientific explanations have been put forward. Some of these have been shown to produce effects similar to ball lightning under laboratory conditions, but it's not yet clear which theory – if any – is correct.

Ball lightning seen from a distance might be mistaken for a UFO

Bright meteors can be mistaken for UFOs by anyone unfamiliar with the night sky

WHAT ELSE MIGHT UFOS BE?

Although the majority of UFOs can eventually be explained in terms of known objects or phenomena, this doesn't mean they all can. And alien spacecraft aren't the only possibilities. A British government report in December 2000 concluded that some UFOs might be plasma phenomena in the Earth's atmosphere not fully understood by current science. Even more way out is the suggestion that UFOs are incursions from other realities or dimensions existing alongside our own.

Circular fallstreak clouds can appear UFO-like in some circumstances

Dr David Clarke is an associate professor at Sheffield Hallam University

THE MINISTRY OF DEFENCE AND UFOS

Since 2008, David Clarke has worked with the National Archives on releasing the MoD's UFO files

Could you give us a quick idea of what the files contain?
There are two sets of files. The first are paper ones transferred to the National Archives under the old 30-year rule. These cover roughly 1950 to 1984, but are very patchy because many earlier records were destroyed. The second set are from 1984 until 2009, when the MoD closed its public UFO desk. Both sets consist of UFO policy, sighting reports and public and parliamentary correspondence.

Looking at the sightings reported by the public, do some of them have obvious explanations?
The vast majority of the 12,000 sightings logged by the MoD have down-to-earth explanations, but some remain unexplained. The truth is they never had resources to do more than a few basic checks on reports, and very few were investigated properly. There are almost as many explanations as there are sightings – everything from paper lanterns to bright planets and space debris. The MoD received 750 reports in 1978, one of the largest totals – this was the same year Spielberg's film *Close Encounters of the Third Kind* was released!

Can you give a couple of examples of sightings that are harder to explain?
One of the most puzzling is the Calvine incident from 1990. Two men saw a large diamond-shaped object hovering above moorland in Scotland and took six photographs. They show the UFO being shadowed by what appears to be an RAF Harrier. But the image in the files is a poor-quality copy. The case was investigated by MoD intelligence, but there's little in the files that reveals the results. The most famous incident in the files is the Rendlesham Forest encounter in Suffolk in 1980. Both cases provide examples of the limitations of these records in that sensitive information has been removed and in some cases destroyed.

WATER ON MARS

Orbiters and rovers have found evidence of a watery past on the Red Planet. But why is this evidence so important?

WORDS JAMES HORTON

DID YOU KNOW? The Perseverance rover touched down on the Martian surface on 18 February 2021

Mars may once have been covered in oceans, and some water may persist on the planet

The fourth planet from our Sun, Mars, is named after the Roman god of war, so dubbed because of its bloody-red colour. In 1897, novelist H. G. Wells wrote in his book *The War of the Worlds* that this colour was owed to organic red weeds that covered the planet's surface. However, when Mariner 9, the first spacecraft to orbit another planet, cruised around the red world, it revealed an endless landscape of dry, barren desert. In stark contrast to an abundant bounty of weed life, the reality of the Red Planet is a desolate biome covered in iron-rich dust and rocks.

But on and underneath the rocky surfaces, chasms and crevices of this world, there's a compelling mystery. The more we look, the more we find evidence that water may once have been abundant on Mars, and some think that liquid water is still hidden there.

Water is believed to be integral to the origin of life. Such is the importance of water that when exploring the Martian landscape, NASA adopted a similar strategy to Earth colonists exploring new lands, opting to 'follow the water'. Looking at the dry and barren surface, this strategy may appear misguided. But today's appearance doesn't mean the world was always this way.

Mars is a cold planet, 1.5 times as distant from the Sun as Earth. It's also smaller than Earth, and thus enjoys less gravity, meaning it only now retains a thin atmosphere. These factors mean that oceans could have once covered swathes of the dusty planet, yet these would be reduced to little or nothing today. Mars spacecraft, both orbiters and rovers, are therefore busy scouring the planet's geology and atmosphere for evidence of a former watery world.

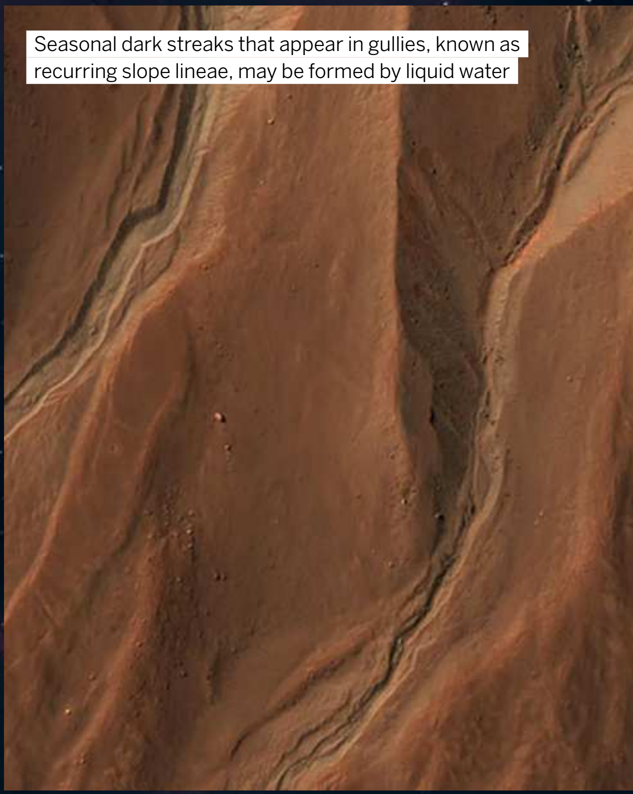
Did you know?
Some meteorites that fall to Earth come from Mars

Geologists on Earth know that the flow of water leaves a powerful impression on the landscape. On a large scale, water carves out riverbeds as it moves across the land. On a smaller scale, water picks up and carries smaller minerals as it flows, slowly polishing them over time into smooth spheroids that are deposited somewhere downstream.

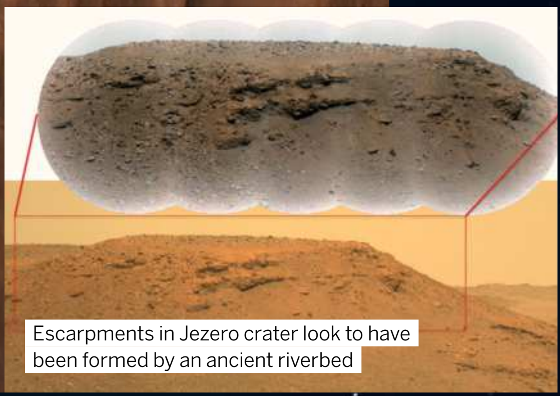
Striking observations from the Mars Reconnaissance Orbiter (MRO) and its predecessors found evidence of large rock formations that appeared to be dry riverbeds.

And the Curiosity rover has observed small, round stones littering a suspected former riverbed. As well as these features, an accidental discovery by the Spirit rover revealed a layer of silica – which is deposited by hydrothermal springs – nearby a suspected former volcanic hydrothermal region. The serendipitous finding reaffirmed for many scientists that the area was once home to a hot spring.

The ancient riverbeds of Mars are long since depleted, but water may have persisted



Seasonal dark streaks that appear in gullies, known as recurring slope lineae, may be formed by liquid water



Escarpments in Jezero crater look to have been formed by an ancient riverbed

in other forms into the modern day. The thin atmosphere would mean evaporated liquid water would soon be lost to space, but water could persist if the cold allowed it to freeze solid, or if it was protected underground. Like Earth, the poles of Mars are the coldest regions on the planet. But unlike Earth, temperatures on Mars can plummet to -150 degrees Celsius. This means that huge sheets of ice cover the poles of Mars. However, carbon dioxide freezes at these extreme temperatures, and approximately 95 per cent of the Martian atmosphere is composed of this molecule. Mars ice may be water ice, carbon dioxide ice or a combination containing both. The European Space Agency's Mars Express probe used infrared scans to help solve this riddle, revealing evidence of water ice existing in a cocktail with Martian dust at the southern pole.

While there may have been abundant oceans in the past and water ice persisting in the present, could there be lingering liquid water on Mars? Tantalisingly, the answer may well be yes. Using radar technology that penetrates the ground, returning signals suggested that bodies of liquid water also existed

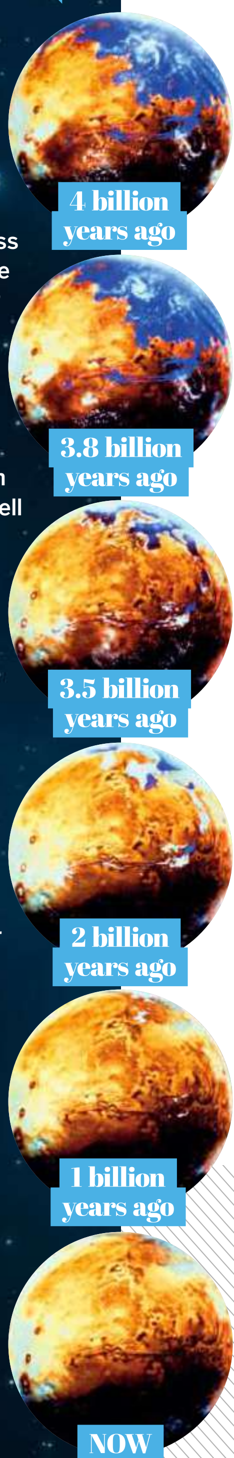
> **"Remnants of water may endure on the Martian surface billions of years after it lost its oceans"**

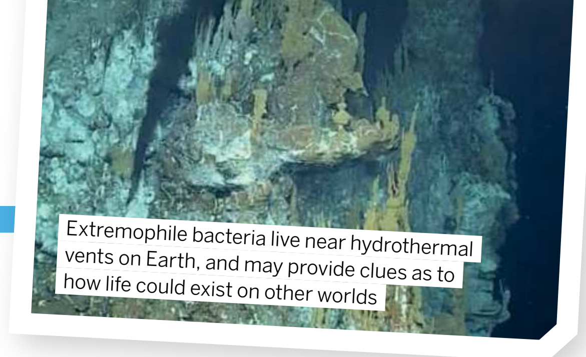
underground the south pole. For water to be liquid at these temperatures it would have to be salty, almost a brine. But could such briny salt water also allow liquid water on the surface?

In 2011, the MRO captured images of dark streaks that appear seasonally in Martian slopes, which flow downhill. While some scientists argue that these streaks are owed to flowing sand, others believe they are owed to subsurface salt water that rises to the surface in more forgiving temperatures. Remnants of water may therefore endure on the Martian surface billions of years after it lost its oceans. The Perseverance rover is carrying this insight into the future of Mars exploration and will use these signatures of water on Mars as a guide for searching for ancient microbial life that may have once blossomed there.

THE HISTORY OF WATER ON MARS

Evidence suggests that Mars was once covered in oceans that were lost several billion years ago



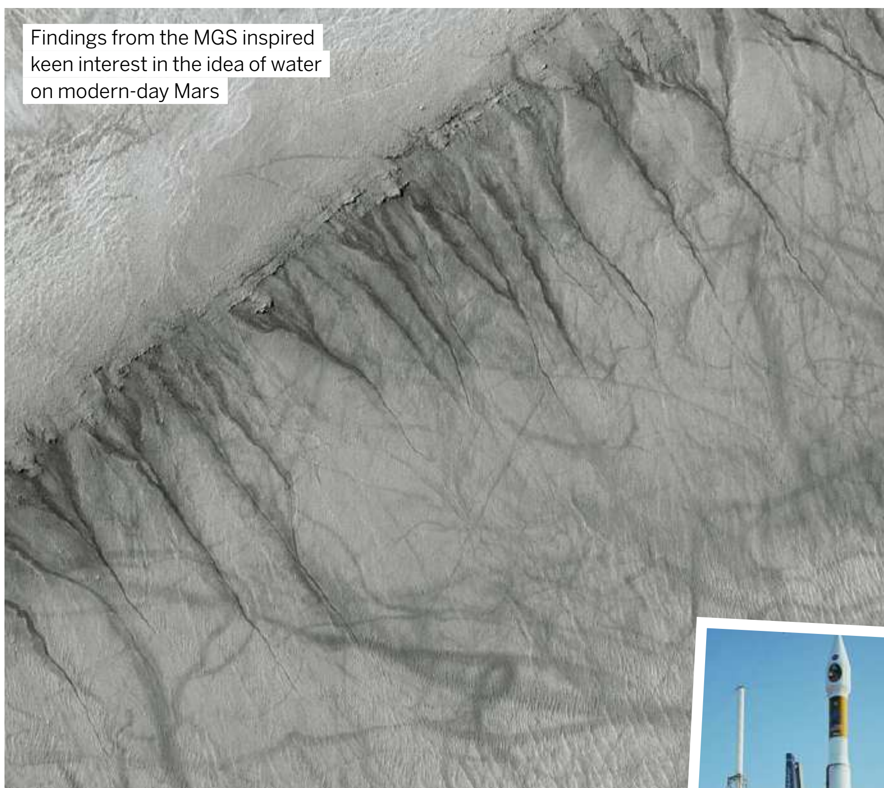


Extremophile bacteria live near hydrothermal vents on Earth, and may provide clues as to how life could exist on other worlds

ASTROBIOLOGY ON MARS

The discovery of alien life would arguably represent the most significant discovery in the history of humanity. Most of the galaxy will likely forever remain out of our reach, but we may only need to peer across to our neighbouring planet to find it. Owing to the potential presence of liquid water, the hope for Mars is that conditions may have been sufficient to allow for the genesis and evolution of microbial life.

The idea of extant microbial life on modern-day Mars is highly suspect due to the pervasive arid and cold climate, which presents a hostile environment for life. However, research into extremophile microbes on Earth may offer clues as to how microbes could endure in salty water under the Martian surface. If microbes on Mars are now extinct, there's still much hope that we can find evidence of the biological relics they left behind, which would show that life could bloom on another world.



Findings from the MGS inspired keen interest in the idea of water on modern-day Mars

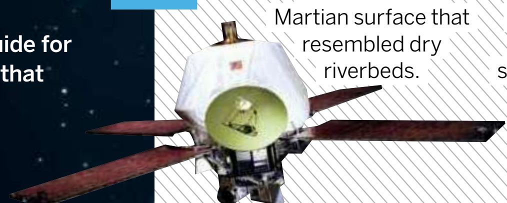
EXPLORING MARS

1971
The orbital craft Mariner 9 photographed chasms on the Martian surface that resembled dry riverbeds.

1997
The Mars Pathfinder mission sent its last batches of data. The rover observed rounded pebbles that resembled minerals shaped in running water.

2000
The Mars Global Surveyor (MGS) probe took photos of gullies in Martian craters, which may have been formed by flowing water.

2005
The Mars Reconnaissance Orbiter (MRO) was launched from Earth, hosting a battery of instruments capable of detecting signatures of water on Mars.



DID YOU KNOW? NASA's policy of following the water is also guiding missions to other worlds in our Solar System

WITNESS TUBES

One of the key mission directives during Perseverance's surface operations is to collect samples for a future mission to bring back to Earth. The rover will need to place the samples in the same designated location on the Martian surface, known as a sample cache. An important control measure is to make sure that scientists don't misinterpret Earth contaminants sent on the rover for something native to Mars. To ensure this doesn't happen, the rover is equipped with witness tubes, similar to sample tubes and opened at the same time. However, these don't collect any samples, instead taking in the ambient atmosphere at the sample site. Only if something is present in the sample tube and absent in the witness tube will it be considered native to the Red Planet.

PERSEVERANCE'S SAMPLING SYSTEM

The latest Mars rover will package up potential evidence of ancient life for a future mission

DEPOSIT
The samples are deposited on the Martian surface for collection by a future mission when the rover reaches a 'sample cache depot'.

SAMPLE CACHE
The sample is transferred to the rover's belly, where it's inspected and sealed using a smaller, interior robotic arm.

DRILL
A large robotic arm attached to the rover's body drills the Martian surface to fill a sample tube.

Did you know?
The Saturnian moon Enceladus may also host liquid water

CAMERAS
Scientists controlling the rover on Earth decide on which samples to collect using cameras attached to the rover's body.

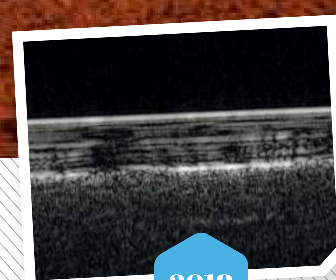
2007
The Spirit rover's broken wheel scratched away Martian soil (regolith), exposing silica – which usually forms in the presence of water – underneath.

2008
The Phoenix lander unearthed chunks of bright material that vanished after a few days; these may have been water ice.

2011
The Mars Reconnaissance Orbiter's High Resolution Imaging Science Experiment (HiRISE) imaged dark streaks on Martian slopes that changed seasonally.

2012
The Sample Analysis at Mars instrument (SAM) affixed to the Curiosity rover heated Martian dirt, finding signatures of water elements in the gases that boiled off.

2015
Lujendra Ojha and his colleagues performed spectral analysis on the dark streaks, which suggested that they were formed by salty liquid water.



2018
The European Space Agency's Mars Express orbiter used ground-penetrating radar to find signatures of underground water ice at Mars' south polar region.

SUPERM
BLACK HOLES

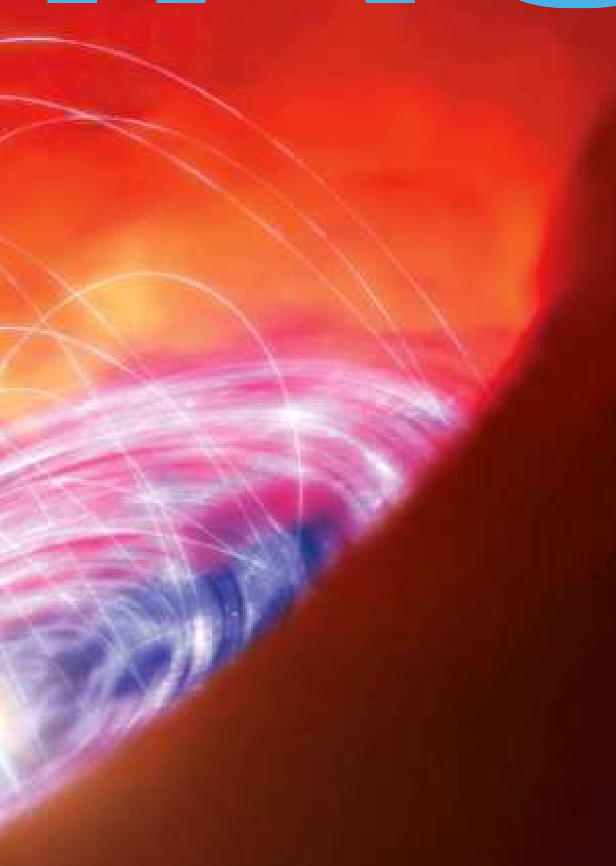
A look at the mysterious giants that lurk at the hearts of most galaxies

WORDS ANDREW MAY

Theoretically, if you compress a sufficient amount of matter into a small enough space, it will create such a powerful gravitational field that nothing – not even light – can escape from it. That's the basic idea behind black holes, and it's so bizarre that for many years scientists thought they couldn't possibly exist in reality. Yet today we know the universe is filled with them – perhaps as many as one for every ten visible stars. A few of those black holes are truly enormous, with masses millions of times greater than the Sun. They're known as supermassive black holes.

Black holes are among the most mysterious and awesome objects in the universe. From a naive point of view, however, anything that isn't a black hole might appear to be the real mystery. If gravity is a force that inexorably pulls objects together, why doesn't any random clump of matter ultimately collapse down to a black hole? The answer is that there are other non-gravitational forces that act in the opposite direction, halting the collapse before it can go all the way. For example, stars are held up by thermal pressure. When that eventually becomes too weak to resist the force of gravity, other forces may come into play to prevent total

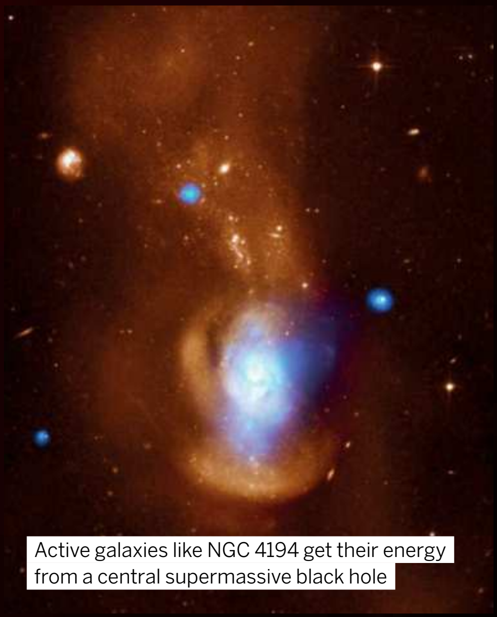
MASSIVE



collapse, resulting in a white dwarf or neutron star forming. But if there's so much matter present that even those forces break down, then gravity finally wins and a black hole is formed. This is the ultimate fate of the most massive stars that started life considerably bigger than the Sun, but it can also happen on an even vaster scale, involving masses millions of times greater than any star. These are the supermassive black holes believed to lurk at the hearts of most galaxies .

It's impossible to observe a black hole directly because, as their name suggests, they don't emit any light or other radiation. But they can be detected via their gravitational effect on visible stars in their neighbourhood, which orbit around the black hole much faster than they would around a normal object of similar size. By measuring the speed of stars close to the black hole, astronomers can estimate its mass. That's how they know the black hole at the centre of our own galaxy has a mass around 4 million times that of the Sun. As big as that sounds, it's really quite tiny compared to the largest supermassive black holes that have been measured, some of which approach 100 billion solar masses.

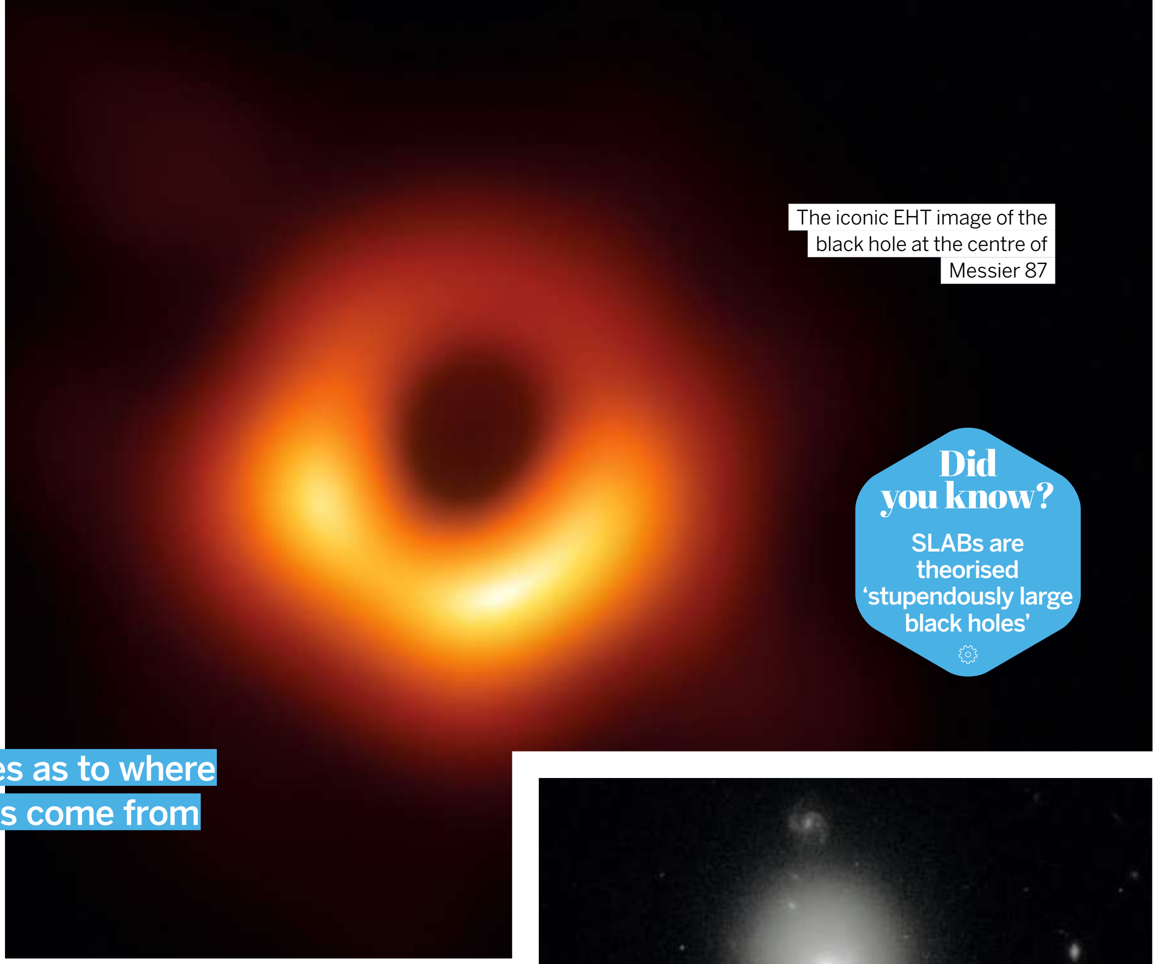
Contrary to their fearsome reputation as gobblers of anything that ventures too close to them, the black holes at the centres of most galaxies lead fairly quiet lives, only giving away their existence through subtle effects on nearby stars. In an active galaxy, however, a supermassive black hole really does live up to its voracious reputation. Surrounded by a swirling 'accretion disc' of rapidly rotating gas and dust, matter is constantly spiralling down into the black hole and being consumed. In the process, the black hole releases enormous amounts of energy, sometimes outshining the rest of the galaxy. It was in one such active galaxy's accretion disc that the Event Horizon Telescope (EHT) succeeded in capturing a direct image of a black hole in 2019. The ominous shadow of Messier 87's 6.5-billion-solar-mass black hole is clearly visible, quite literally as a 'black hole', at the centre.



Active galaxies like NGC 4194 get their energy from a central supermassive black hole

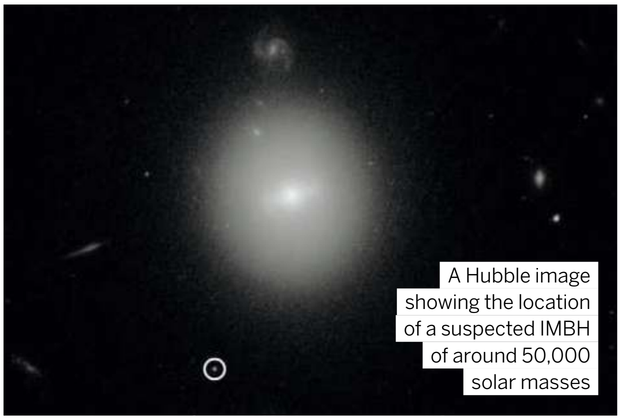
HOW THEY FORM

There are several theories as to where supermassive black holes come from



The iconic EHT image of the black hole at the centre of Messier 87

Did you know?
SLABs are theorised 'stupendously large black holes'



A Hubble image showing the location of a suspected IMBH of around 50,000 solar masses

Films often portray black holes as giant cosmic vacuum cleaners, relentlessly sucking in material until there's nothing left. If that was how real black holes worked, there would be no mystery as to where the supermassive kind came from: once an 'ordinary' black hole had formed from stellar collapse, it would simply grow and grow until it reached enormous size. But real black holes don't suck matter in like this; they merely attract it with the same law of gravity as a normal object of the same mass. Their exceptional nature comes from the fact that they're super-condensed and the force of gravity increases as distance decreases, so it's possible for an orbiting object to stray into a region where gravity becomes incredibly strong. At larger distances, however, a black hole's gravity is perfectly normal. But if a black hole is incapable of sucking in distant matter, how does it ever grow to supermassive size? At present, no one knows the answer to this, although there are several promising theories.

Although they may not be the rapacious predators portrayed in science-fiction, we know that some black holes do absorb new material, and that's what's going on in the accretion discs of active galaxies. Occasionally pairs of black holes crash into each other and merge to produce a single, larger black hole, and we know that from evidence of gravitational waves, which have been observed on a regular basis since they were first discovered in 2015. But accretion and mergers, while undoubtedly part of the solution, aren't enough in themselves to explain the observational evidence for supermassive black holes. That's because we know the first active galaxies, which must have been powered by central black holes, were formed very early in the

SUPERDENSE OBJECTS IN SPACE

There's a whole spectrum of compact astronomical objects, culminating in supermassive black holes

WHITE DWARFS

SOLAR MASSES: UP TO ONE

The end result of stellar evolution for low-mass stars like the Sun, these consist of a dense plasma of atomic nuclei and electrons.

NEUTRON STARS

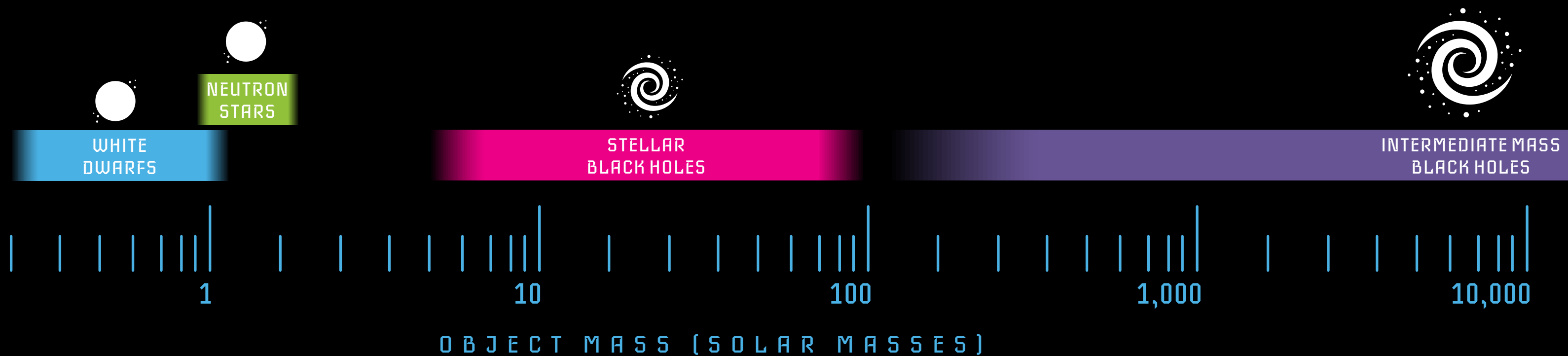
SOLAR MASSES: AROUND 1.4

Formed from stars between 10 and 25 solar masses, these are composed almost solely of neutrons – particles that are normally just one component of an atomic nucleus.

STELLAR BLACK HOLES

SOLAR MASSES: 5 TO 50

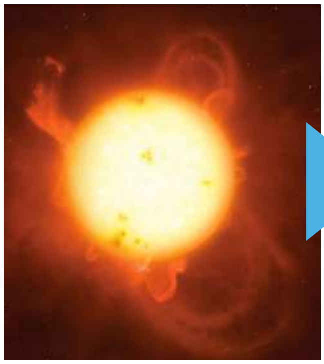
Stars that are too heavy to stop at the neutron stage collapse all the way to a black hole, with all their mass concentrated into a single point.



DID YOU KNOW? If supermassive black holes lie at the hearts of most large galaxies, there are 100 billion of them

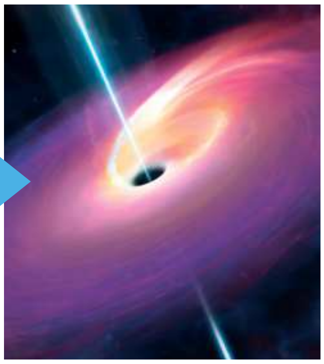
HOW BLACK HOLES GROW

The earliest black holes to form in the universe will be much bigger today



1 GIANT STAR
The first generation of very massive stars, hundreds of times as massive as the Sun, would have burnt through their nuclear fuel very quickly.

2 SEED BLACK HOLE
The star collapsed down to a black hole of tens of solar masses, which then acted as a seed for the creation of a much larger black hole.



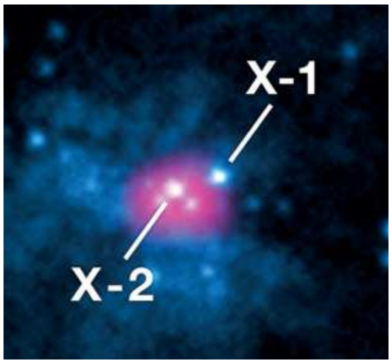
3 ACCRETION
Over billions of years, gas and dust spiralling into the black hole increased its mass, but this isn't enough to explain supermassive black holes.

life of the universe. For example, a supermassive black hole of a billion solar masses is believed to have existed in one galaxy more than 12 billion years ago, around 90 per cent of the way back in time to the Big Bang.

It's possible the stellar life cycle, which is so crucial to the standard model of black hole formation, had nothing to do with the creation of the oldest supermassive black holes. Instead they may have formed almost immediately from the gravitational collapse of an enormous cloud of gas, one that already contained as much matter as millions of stars. According to this theory, a 'direct-collapse black hole' would have taken around 150 million years to form – the blink of an eye in cosmic terms. Another hypothesis invokes the idea of primordial black holes, theorised to have been created in the Big Bang itself. These are sometimes proposed as a possible explanation for dark matter and are generally assumed to have been quite small in size. However, they might have served as the basic seeds from which present-day supermassive black holes grew.

INTERMEDIATE MASS BLACK HOLES

There's good observational evidence for two types of black hole: those that formed from collapsing stars, which can be several tens of solar masses, and the supermassive kind, which are millions or billions of solar masses. This leaves a gap, from a hundred solar masses up to several hundred thousand, where the evidence is much scarcer. Dubbed intermediate mass black holes (IMBHs), these could be produced by any of the mechanisms proposed to explain supermassive black holes, whether by mergers, accretion, collapsing gas clouds or primordial black holes. It's possible that IMBHs could be found at the centres of very small galaxies, and there's some evidence this is the case. It's also possible that IMBHs exist in larger galaxies, but away from the centre. A bright source of X-rays in Messier 82 may be associated with an IMBH of around 400 solar masses.



A bright X-ray source in galaxy Messier 82, labelled X-1, may be an IMBH

INTERMEDIATE MASS BLACK HOLES

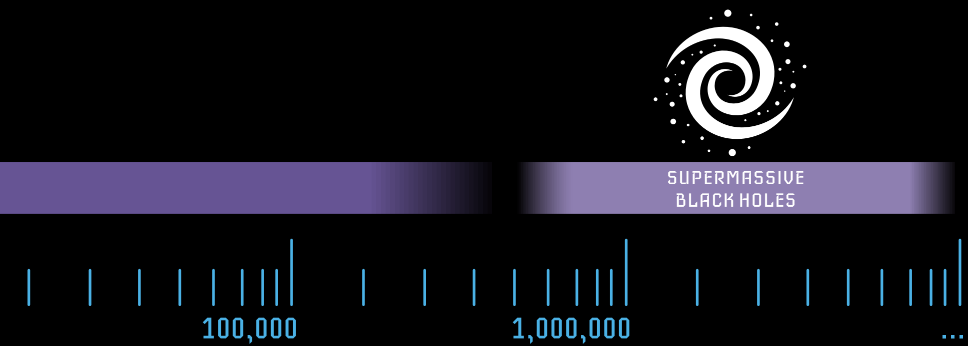
SOLAR MASSES: 100 TO 100,000

The most elusive kind of black hole, these are nevertheless believed to exist, for example in the centres of very small galaxies.

SUPERMASSIVE BLACK HOLES

SOLAR MASSES: OVER 1,000,000

These monster black holes are known to lurk in the centres of most large galaxies, and there's no theoretical limit to how large they can grow.

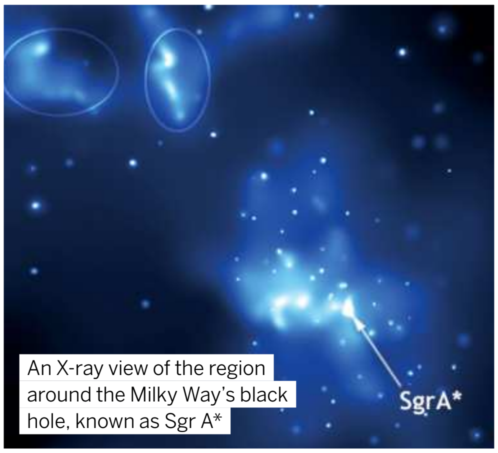


A broader view of Messier 87, showing a jet emanating from the central black hole

MAKING AN ACTIVE GALAXY

How the infalling of material powers black holes

Artist's impression of a quasar powered by a supermassive black hole



An X-ray view of the region around the Milky Way's black hole, known as Sgr A*

In normal galaxies, most of the light we see comes from the billions of stars they contain, but active galaxies are different. They radiate huge amounts of excess energy across the whole of the electromagnetic spectrum, all appearing to emanate from the very central region, or nucleus, of the galaxy. Perhaps unsurprisingly, the underlying power source for these 'active galactic nuclei' is believed to be the central black hole. Yet most ordinary galaxies also likely possess supermassive black holes, without displaying any unusual activity. So what makes an active galaxy so active?

The answer is that active galaxies involve matter constantly falling into the black hole, emitting large amounts of energy in the process. Technically known as accretion, this doesn't happen in the way you might imagine, with the matter falling straight down into the black hole. That's because the material has rotational motion that – at least temporarily – counteracts the pull of gravity, just as an orbiting satellite is prevented from falling to Earth. Instead the material forms a rapidly spinning 'accretion disc' around the black hole. But it does fall in eventually, because friction within the disc gradually slows the rate of spin, causing the material to spiral inexorably inwards.

In some active galaxies, the accretion process blasts out two narrow jets of high-energy particles in opposite directions. These jets, travelling at almost the speed of light, can sometimes extend for hundreds of thousands of light years. But what we actually see from Earth depends on how we're viewing the galaxy relative to the direction of the jet – and if it has a jet at all. Another complicating factor is the presence of a dusty, doughnut-shaped region called a torus around the accretion disc. This may obscure our view of the active galactic nucleus if we view it from certain angles.

Did you know?
Quasar stands for quasi-stellar radio source

There's quite a zoo of active galaxies: some of them differing intrinsically, others only because we view them from different directions. The brightest of all are quasars, thought to have been particularly common in the early universe when there was more gas available for accretion. Another bright type is a blazar, which is what we see when we view an active galaxy's jet head-on. At the more 'normal' end of the active galaxy spectrum are Seyfert galaxies, which are active spiral galaxies, and radio galaxies, which are active ellipticals.

But is it possible for a non-active galaxy to become an active one? The main requirement is for a sufficient amount of fresh material to be accreted onto the black hole. That's something that's unlikely to happen in the normal course of events, with one important exception. That's the case where two galaxies crash into each other and coalesce into a single, larger galaxy. Things can get pretty chaotic in such situations, and it's possible new material may find its way to the vicinity of the central black hole, or more likely two black holes before they eventually merge and create a brand-new active galaxy.

WHEN BLACK HOLES COLLIDE

Galaxy collisions aren't uncommon. When they occur, the central black holes eventually merge too

1 MERGING GALAXIES
Two galaxies crash into each other, initially producing a confused mess of material, but then settling down to become a single, merged galaxy.

2 TWO BLACK HOLES
The supermassive black holes that started at the centres of the original galaxies gradually spiral towards each other, eventually coalescing into a single black hole.

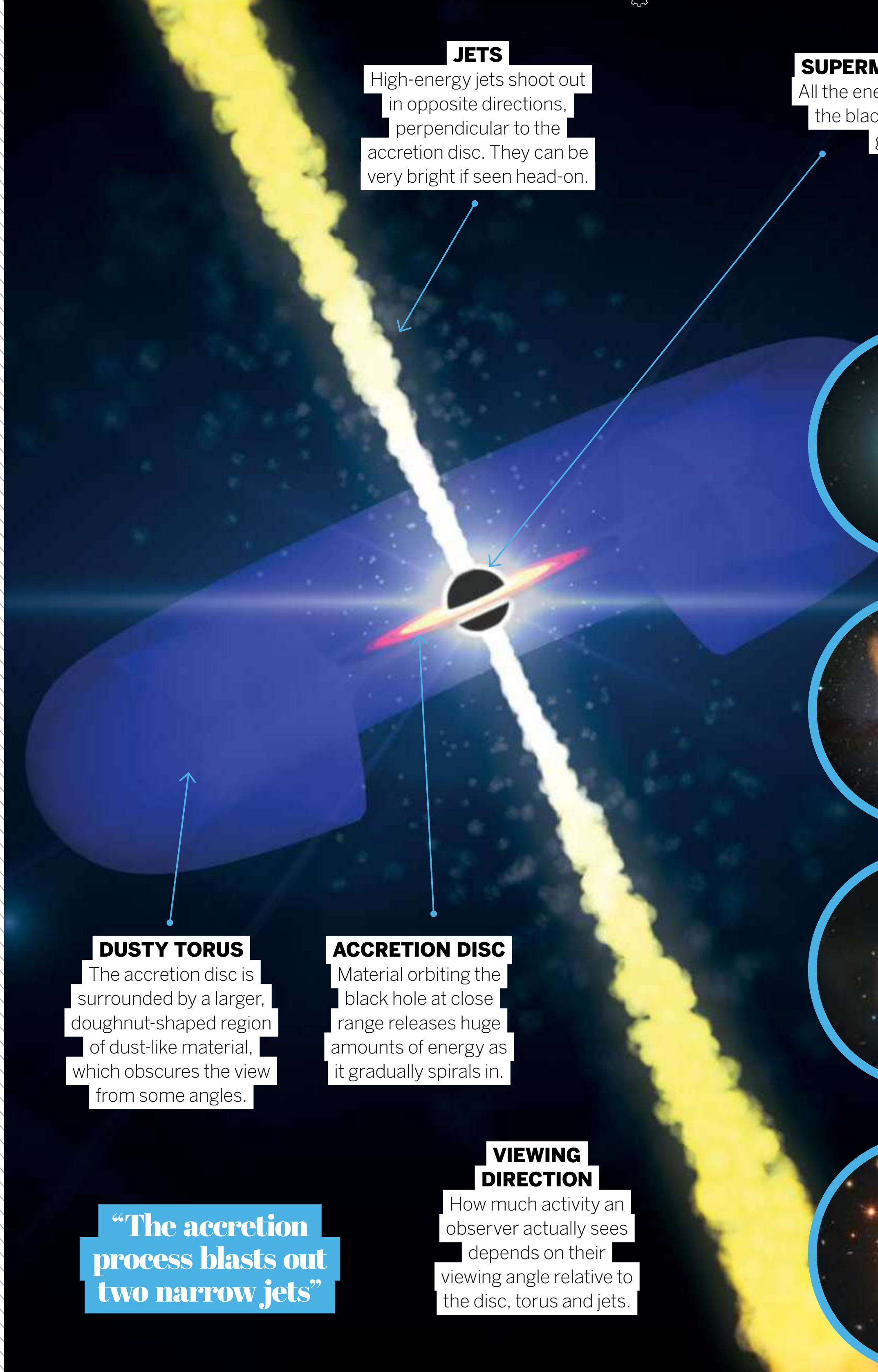
3 HIGH-ENERGY JET
The combined black hole may cause the core of the merged galaxy to eject streams of hot gas containing particles travelling close to the speed of light.

4 VISIBLE CONSEQUENCES
The newly merged supermassive black hole gives its presence away through the release of gravitational waves and high-energy electromagnetic radiation.

DID YOU KNOW? Accretion of matter onto a black hole is the most efficient energy-production mechanism in the universe

ACTIVE GALACTIC NUCLEI

In an active galaxy, all the action takes place near the central black hole



"The accretion process blasts out two narrow jets"

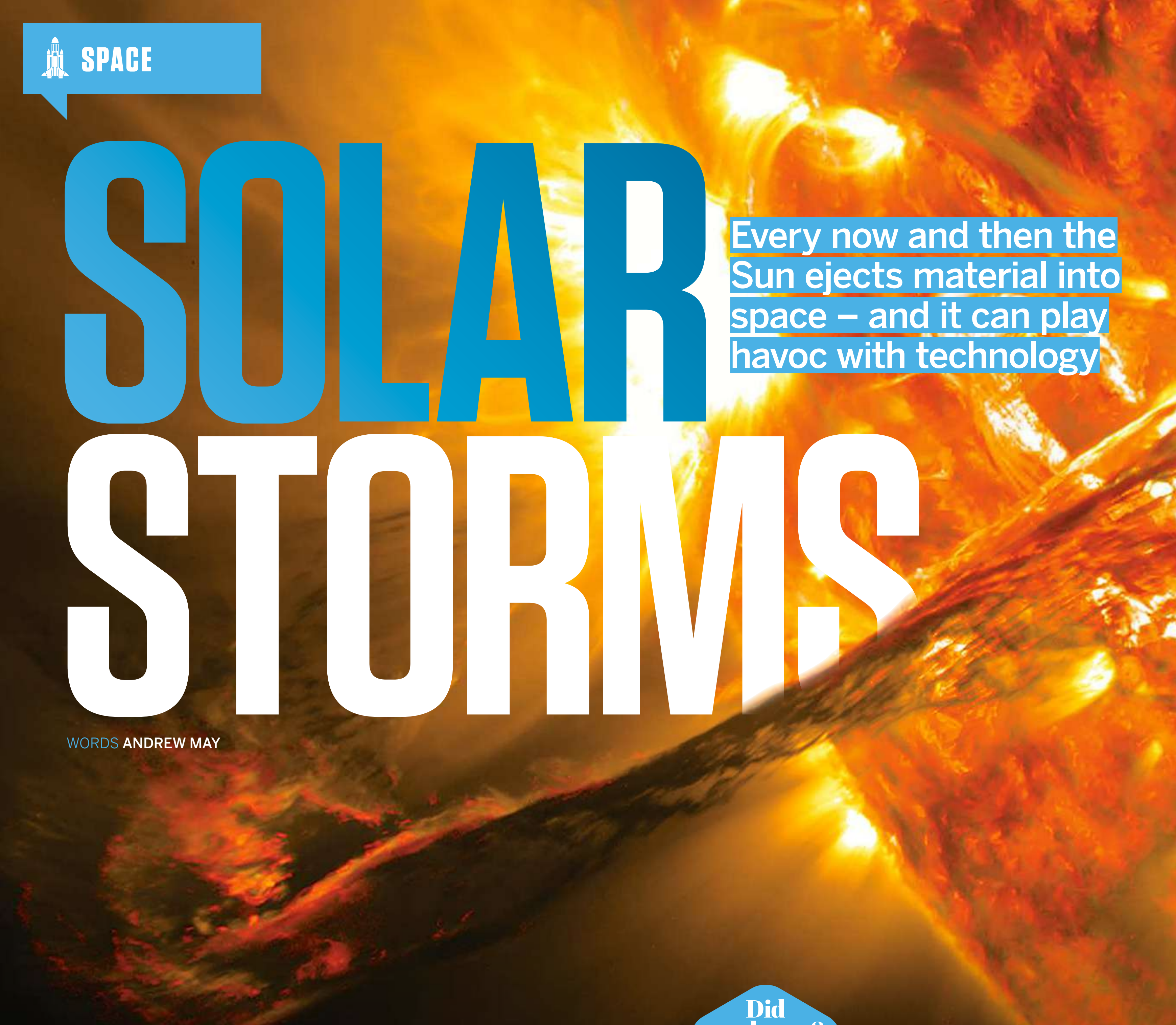
SUPERMASSIVE EXAMPLES

LEO I DWARF GALAXY
Although this tiny galaxy is only about 20 million solar masses in total, its central black hole is proportionately huge at around 3 million solar masses.

CENTAURUS A
This huge elliptical galaxy – a cosmic neighbour at just 13 million light years away – is a powerful radio emitter thanks to the 55-million-solar-mass black hole at its centre.

NGC 7727
The product of two merging galaxies, NGC 7727 still retains two supermassive black holes – of 154 and 6.3 million solar masses – just 1,600 light years apart near its centre.

ABELL 2261
This cluster of galaxies is estimated to have a black hole of up to 100 billion solar masses near its centre. Frustratingly, its exact location continues to elude detection.



SOLAR STORMS

Every now and then the Sun ejects material into space – and it can play havoc with technology

WORDS ANDREW MAY

Fortunately for life on Earth, the Sun is remarkably constant in the heat and light it radiates. In more subtle ways, however, our star is much more capricious. It can blast matter out into space in a way that for most of human history people have been blissfully unaware of. Today, though, such phenomena, known as space weather, can have drastic effects on the satellites and electronic technology we rely on. The origins of space weather can be traced to contortions in the Sun's magnetic field, leading to dark blotches, or 'sunspots', on its surface. It's from these spots that solar flares, coronal mass ejections (CMEs) and other electromagnetic phenomena can emerge – with potentially hazardous consequences for our technological way of life. Sunspot activity rises and falls on an 11-year cycle, and we're currently approaching the next solar maximum in 2025. Now is a good time to look at the worst space weather that the Sun can throw at us, in the form of solar storms.

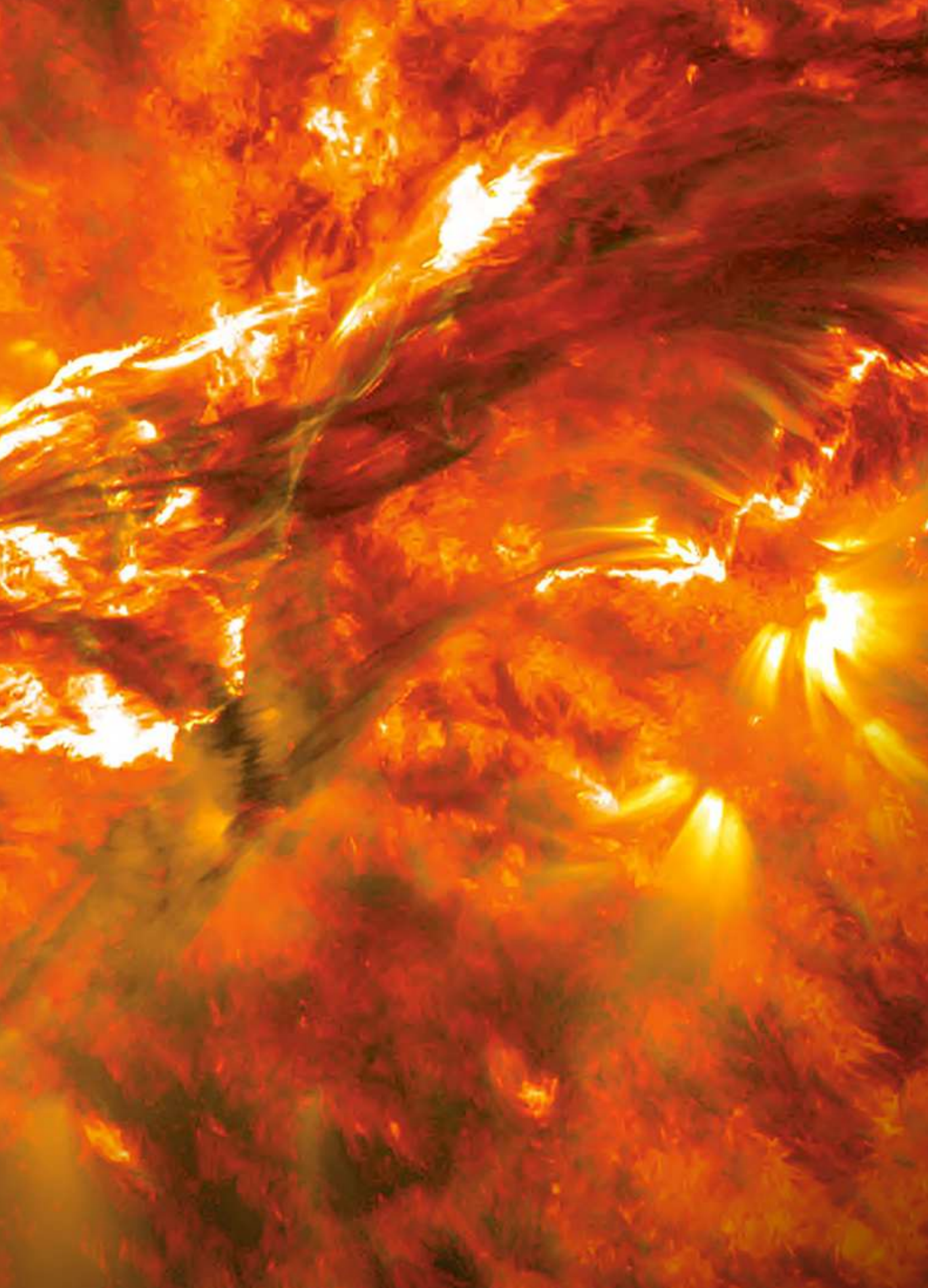
While space weather ultimately originates on the Sun, the term 'solar storm' refers to occurrences on or near our planet, when material thrown out by the Sun reaches us. There are two distinct types of solar storms: geomagnetic storms and solar radiation storms. The first – and most important – of these occurs when a clump of solar material, called a coronal mass ejection, disrupts the Earth's magnetic environment. The second refers to a stream of much faster moving particles ejected by the Sun. As dangerous as the latter sounds, we're largely protected from the effects by the geomagnetic field, as are the majority of satellites in Earth orbit. As a consequence, solar radiation storms are only a really serious problem for deep-space missions. The largest CMEs can contain billions of tonnes of solar material and fly out from the Sun at up to 1,865 miles per second. They contain an embedded magnetic field, and it's this that can play havoc with the Earth's own magnetic field if and when it makes contact.

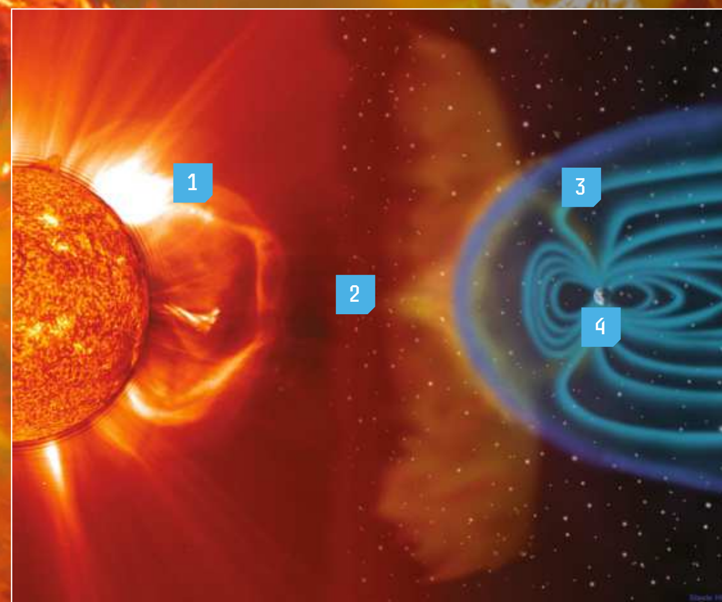
We know that this has been happening since time immemorial; a study reported in January 2022 revealed that a powerful solar storm which pummelled Earth 9,200 years ago left radioactive particles in the ice deep below Greenland that are still there to this day. An earlier study from 2020 suggested

Did you know?

The fastest CMEs can reach Earth in about 15 hours

DID YOU KNOW? Sunspots big enough to be seen with the naked eye were recorded by Chinese astronomers over 2,000 years ago





MASSIVE EJECTION

If one heads our way, a really large CME could cause disruption on Earth

1 CORONAL MASS EJECTION
Part of the Sun's outer corona is blasted out into space.

2 CME TRAVELS THROUGH SPACE
The CME may not be heading our way, but if it is it will take two to four days.

3 EARTH'S MAGNETIC FIELD
This deflects much of the material in the CME, preventing it from reaching Earth.

4 EARTH'S SURFACE
The effects of a really powerful CME can break through the magnetic field and disrupt electrical systems.

that severe geomagnetic storms occurred in 42 of the preceding 150 years – far more often than had previously been thought.

Perhaps the most famous solar storm of all occurred at the beginning of September 1859, just a few months before the solar maximum of 1860. During August 1859, astronomers around the world had been watching with fascination as the number of sunspots grew, among them Richard Carrington in Redhill, Surrey. On 1 September as he was sketching the sunspots, he was lucky enough to see a sudden flash of light – a solar flare – emanate from them. It was almost certainly accompanied by a CME, because the next day Earth experienced an unprecedented geomagnetic storm, with telegraph systems going haywire and auroral displays, normally confined to the most northerly latitudes, visible in the tropics. Carrington put two and two together and realised that the solar flare he'd seen was almost certainly the cause of this massive geomagnetic disturbance – a connection that had never previously been made. The solar storm of 1859 is now known as the Carrington event in his honour.

Carrington's drawing of sunspots at the peak of the Carrington Event in 1859

Did you know?
The UK's Met Office provides space weather alerts

WEIGHING UP THE RISKS

America's National Oceanic and Atmospheric Administration ranks geomagnetic storms on a scale running from G1, causing an increase in auroral activity and minor fluctuations in power supplies, up to G5, which includes extreme cases like the Carrington event. In the middle of the scale, G3 storm warnings are relatively common; there was one at the end of March 2022. Even a G2 event is capable of causing havoc, like when SpaceX lost 40 satellites in February 2022 when a G2 storm prevented them reaching their intended altitude. While solar storms rarely pose a direct threat to human life, there's a risk they can impact safety-critical systems via electromagnetic effects – from space-based communications, navigation and weather forecasting services to electrical power distribution at ground level.


Satellites are particularly vulnerable to the effects of solar storms

SOLAR STORMS AND TECHNOLOGY

Severe space weather events can cause widespread disruption to satellites, aircraft and ground-based systems

1 CORONAL MASS EJECTION
A CME consists of material blasted out from the surface of the Sun. This outburst can sometimes head in the direction of our planet.

2 SOLAR PANEL DEGRADATION
Space weather takes a steady toll on a satellite's solar panels, which generate less and less power over time.

3 SATELLITE DAMAGE
Electronic systems in satellites can also suffer damage, especially during severe solar storms.

4 ASTRONAUT IRRADIATION
Although astronauts are subject to relatively low levels of radiation, it can have a cumulative effect on long-duration missions.

5 NAVIGATION ERRORS
Solar storms can disrupt satellite navigation services, causing serious consequences for aircraft and other vehicles that rely on them.

6 CREW AND PASSENGER IRRADIATION
This is only a serious hazard for people who spend a lot of time flying at high altitude.


A composite image of the Sun produced by the Solar Orbiter spacecraft in March 2022

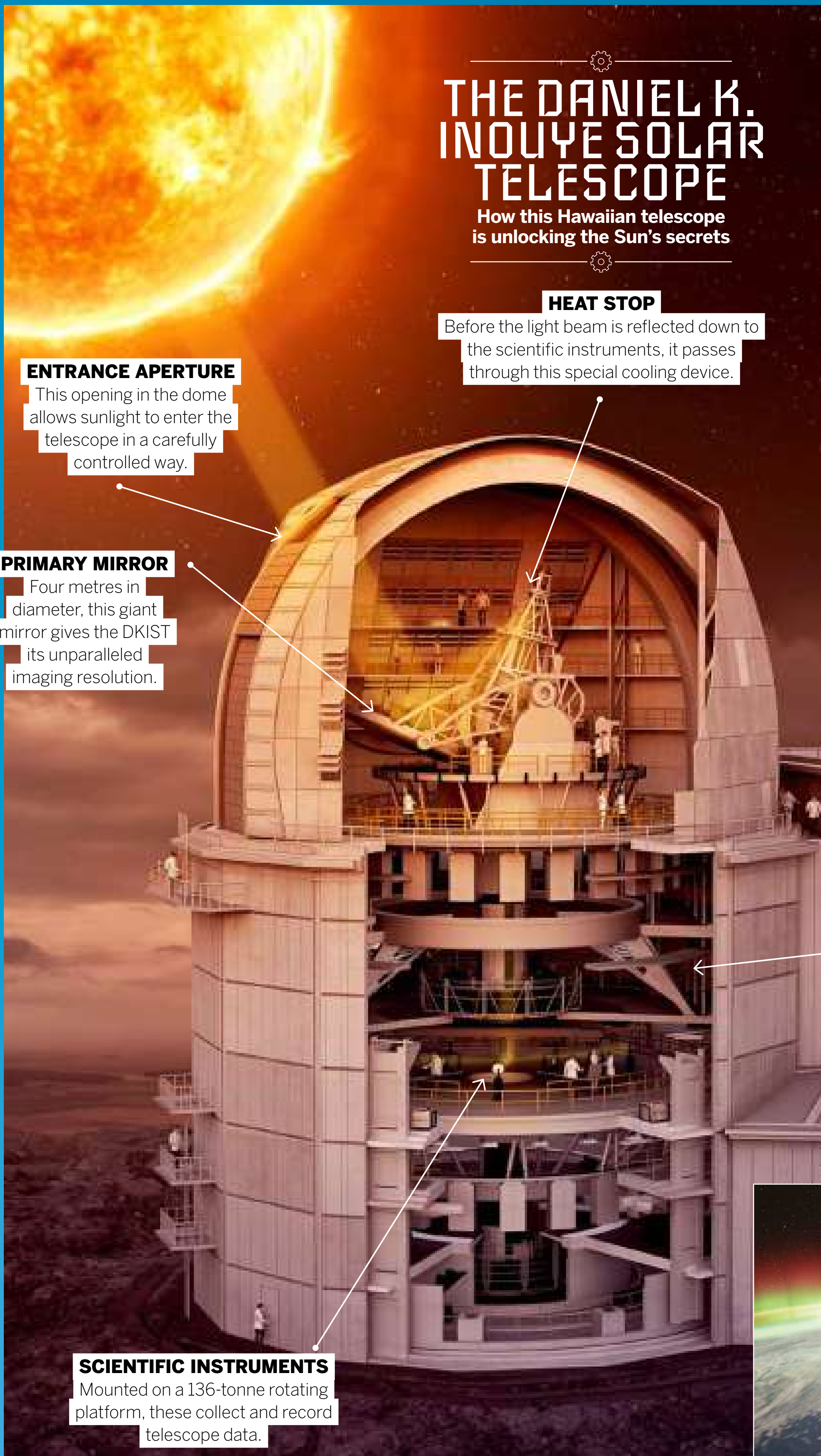
7 SATELLITE RECEPTION
Satellite communication systems, including satellite TV, can also fall victim to space weather events.

8 POWER GRID
A solar storm can induce stray currents in electrical power lines, leading to disruption of power supplies.

9 AURORA BOREALIS
On a positive note, solar activity can produce spectacular auroral displays at high latitudes.

THE DANIEL K. INOUYE SOLAR TELESCOPE

How this Hawaiian telescope is unlocking the Sun's secrets



FORECASTING SOLAR STORMS

A solar storm would only be really disastrous if it hit without warning, before critical systems could be suitably protected. For this reason, an increasing number of satellites and space probes – such as the European Space Agency's Solar Orbiter – are dedicated to observing the Sun. On the ground, observatories around the world are keeping a close lookout for signs of unusual solar activity.

Solar astronomy took a huge step forward in February 2022 with the opening of the Daniel K. Inouye Solar Telescope (DKIST) in Hawaii. As the world's most powerful solar telescope, it combines a giant, four-metre-diameter primary mirror with state-of-the-art adaptive optics which cancel out the distorting effects of the atmosphere to provide super-high-resolution images of exactly what's happening on the Sun's surface.

Aurora borealis as seen by astronauts on board the International Space Station

CAN WE CREATE ARTIFICIAL GRAVITY?

Discover the technology that could provide more natural spacecraft environments for future space exploration missions and space tourism

WORDS ROBERT LEA

Depictions of space travel in science-fiction are replete with scenes set on craft travelling through space with the occupants enjoying the comforts of simulated Earth-like gravity. This concept isn't just limited to TV shows like *Star Trek*, however. Real-world researchers are working on methods to create artificial gravity in space. Not only would this simplify the next era of space exploration, making tasks more straightforward, but it is crucial for potential space tourism – and the need for artificial gravity goes beyond convenience.

The effects of microgravity in space can actually be harmful to humans, so as we look at longer crewed missions, including journeying to Mars, artificial gravity could be essential to our astronauts' health. In his 1905 theory of special relativity, Albert Einstein said that gravity and acceleration are actually indistinguishable. That means that in a rocket travelling at 9.81 metres per second squared – the downward acceleration of gravity here on Earth – an astronaut would feel their body anchored to the floor just like it is on their home planet. The problem is you can't always be accelerating at this rate during a real space journey or stay, especially if you're onboard an orbiting space station. Fortunately, there is more than one form of acceleration – and by using centrifugal force we can generate something equivalent to gravity on Earth.

One possible way of creating artificial gravity in space is by utilising a technology called an O'Neill cylinder. Named after the physicist who proposed them, Gerard O'Neill, this consists of a pair of massive cylinders that rotate in opposite directions, allowing them to be permanently directed toward the Sun, replicating gravity. Jeff Bezos, the owner of space-exploration company Blue Origin, has proposed O'Neill cylinders as the basis of floating space colonies allowing vast numbers of humans to live in orbit.

Aside from being a long way from any kind of practical application, at over 32 kilometres long and 6.5 kilometres in diameter – designed to house several million people – O'Neill cylinders are way too big for most applications smaller than colonies in space. Researchers at the University of Boulder Colorado have devised a smaller-scale alternative – isolated rotating systems that could fit inside the rooms of more readily viable spacecraft. While this wouldn't provide artificial gravity for the whole craft or station, it would allow space travellers to retreat to a specific area and spend some time experiencing a gravitational field more like that of Earth.

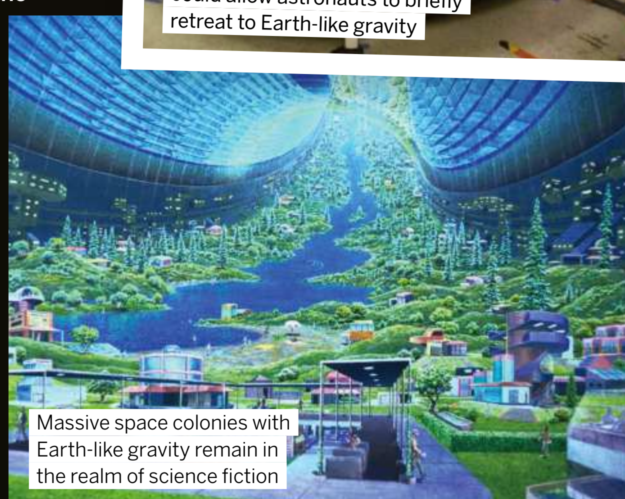
The system also uses centrifugal acceleration replicating a gravitational field of 1g – the same as that on Earth – with astronauts lying down on a short-radius centrifuge for a quick spin. Spinning astronauts might not be the ideal solution, however, as anyone who has ridden the teacups one too many times can tell you, this comes with its own adverse health effects.

Aside from vehicles with one rotating room, other ideas for providing artificial gravity have included long spinning stick-like vehicles 100 metres across with a nuclear reactor on one end and a crew compartment on the other for journeys to Mars, but these have had engineering issues preventing their application so far. The first artificial gravity device in space could be the prototype gravity ring of the proposed Voyager Space Station.

Did you know?

Nautilus X was a centrifuge craft that didn't clear its design stage

Testing out a centrifuge that could allow astronauts to briefly retreat to Earth-like gravity

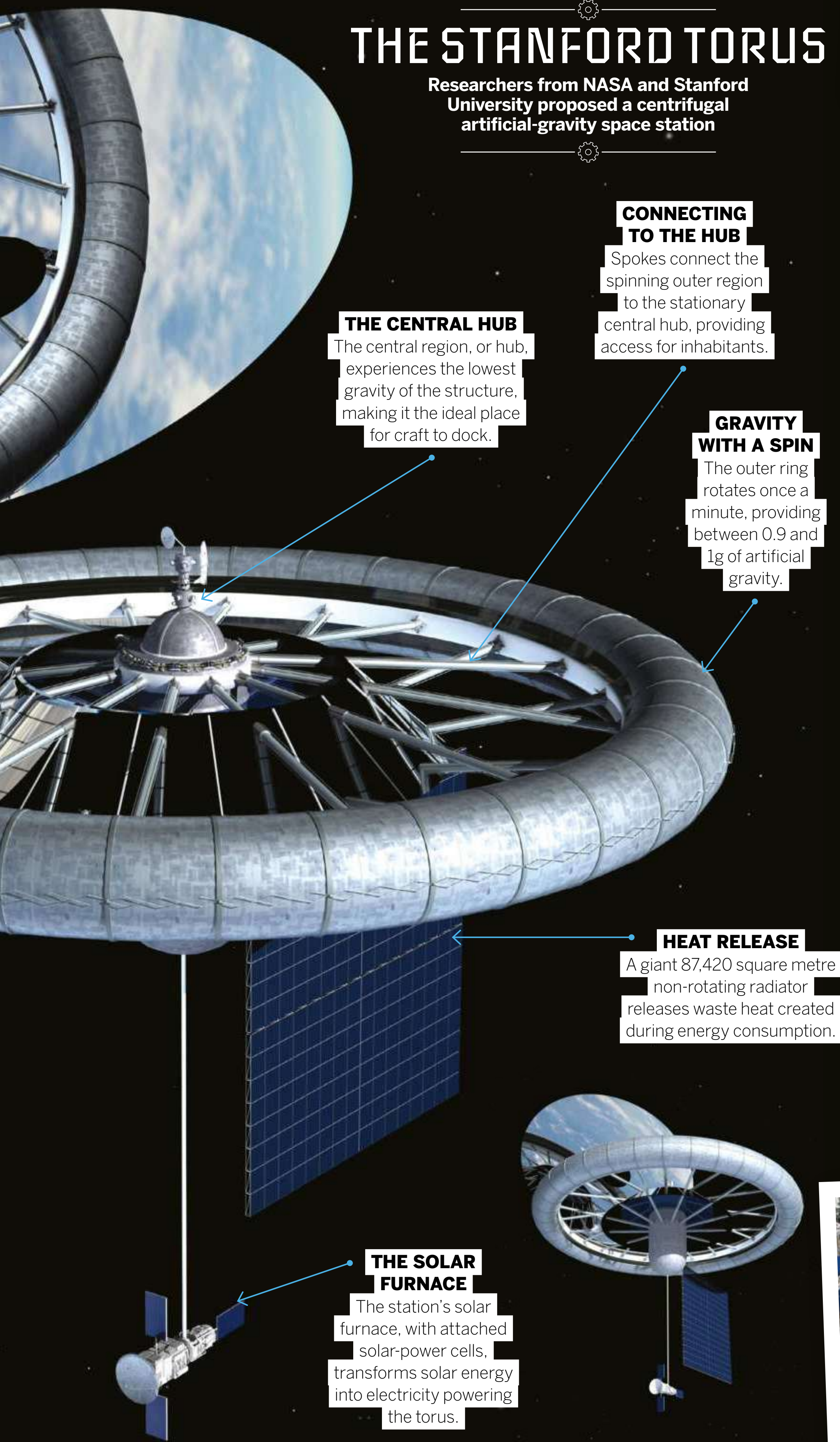


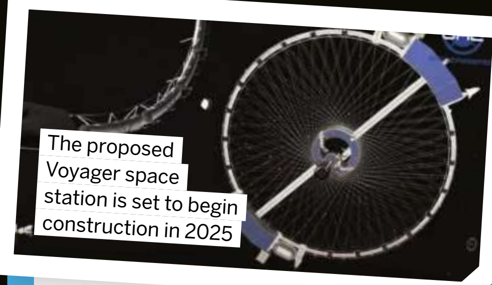
Massive space colonies with Earth-like gravity remain in the realm of science fiction

DID YOU KNOW? Rejected ideas for artificial gravity have included magnets in astronauts' boots

THE STANFORD TORUS

Researchers from NASA and Stanford University proposed a centrifugal artificial-gravity space station




The proposed Voyager space station is set to begin construction in 2025

THE VOYAGER SPACE STATION

The Voyager Space Station is a planned rotating-wheel space station set to begin construction in 2025. Pioneered by the Orbital Assembly Corporation (OAC), Voyager will differ from the International Space Station in two key ways: it will be open to the public and it will have artificial gravity. Placed in a low-Earth orbit, the space hotel will rotate rapidly enough to generate artificial gravity for its 400 occupants. If the station is completed as currently planned it will become the largest human-made structure ever placed into orbit.

The first steps of the project will include the creation of a prototype gravitational ring to improve that artificial gravity in space is viable. The 60-metre-diameter ring will generate gravity equivalent to roughly 40 per cent that of Earth's, or about the same as the gravity of Mars.

HEALTH EFFECTS OF MICROGRAVITY

Establishing artificial gravity could be key to protecting the health of astronauts on long-term space missions. For five decades NASA's Human Research Program (HRP) has studied the effects of microgravity on the human body. They've found that deprived of the gravity of Earth, weight-bearing bones lose on average 1 to 1.5 per cent of mineral density during every month of spaceflight. Muscle mass is lost more rapidly in microgravity than it is on Earth. In addition, during spaceflight fluids in the human body can shift upwards putting pressure on the eyes that potentially lead to vision issues.


NASA astronaut Karen Nyberg uses a device to check eye health potentially impacted by microgravity

ENVIRONMENT

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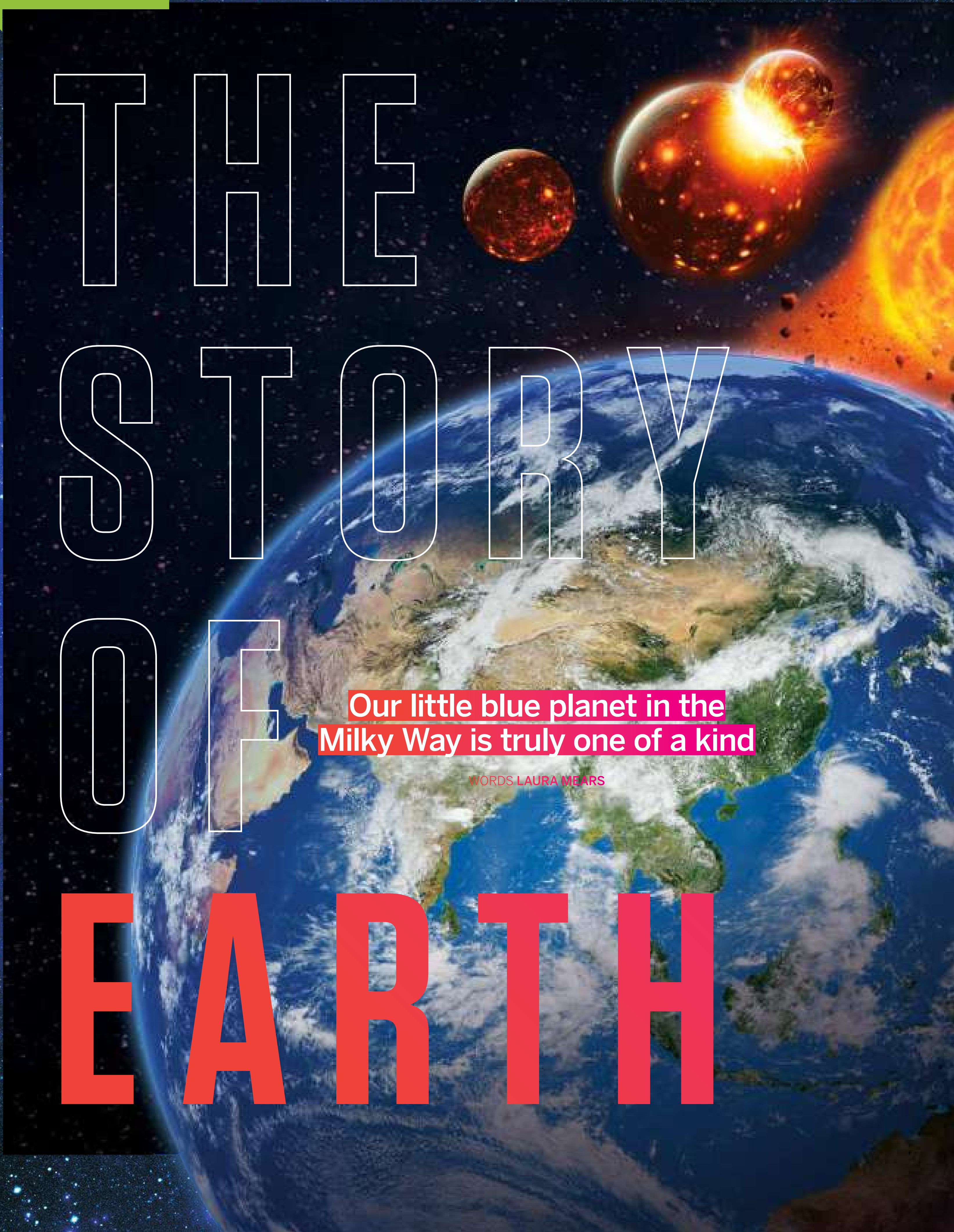


THE STORY OF EARTH

Our little blue planet in the Milky Way is truly one of a kind

WORDS **LAURA MEARS**

As far as scientists know, Earth is the only living planet in the galaxy. Born 4.6 billion years ago from a cloud of cosmic dust and gas, our 7,917.5-mile-diameter ball of rock is home to nearly 9 million different species – and has hosted many more millions since life began. The amount our planet has achieved over its relatively short life span is astonishing. But its journey from a lifeless rock to a paradise island in the cosmos hasn't been easy.

Earth wasn't one of the first planets in the universe – in fact, it's relatively young. Our Sun is a second-generation star, one of a group called Population I. It was born out of the remnants of much older stars after they ran out of fuel.

When the universe began 13.8 billion years ago, the only elements were hydrogen and helium. These lightweight gases formed the first bright, hot stars. Some of these stars had gas planets, but they didn't have rock or metal – as they didn't exist yet – and without those, life was impossible. The elements life needed were forged inside those early stars.

The heat and pressure within squashed the lightweight gases together to form the first 26 elements in the periodic table, up to and including iron. These are the elements that now make up the bulk of planet Earth, and its many inhabitants.

When those first stars ran out of fuel, they stopped fusing elements and started to collapse. Some became so unstable that they exploded. The blasts were so violent that they created even heavier elements, like gold and radioactive uranium, before showering the contents of the dying stars into space.

After the dust of the explosions settled, all that was left were clouds called nebulae. It was from one of these clouds that the Solar System emerged. Earth, and everything on it, is literally made of stardust.

Most of the rock that makes up the outer surface of our planet was forged in the first stars of the universe. These elements include oxygen, silicon, aluminium, iron, calcium, sodium, potassium and magnesium. Underground in the flowing rock of the mantle are more stellar elements – silicon, magnesium and iron – and right at the centre, in the liquid core, is a mixture of molten iron and a supernova element, nickel.

In its earliest days, Earth was just a hot rock in a lifeless star system. But the star-forged elements it contained gave it the power to become so much more. Ancient hydrogen combined with oxygen to make rain, coating the planet in vast oceans. Those oceans dissolved minerals from the first stars, becoming a salty chemical soup. Violent weather, volcanic activity and radiation from the Sun provided the heat and sparks to jolt that soup into life, and that changed our planet forever.

Every living organism on Earth is made of recycled stars, and most of them contain supernova dust, too. Inside your own body, iron allows your blood cells to carry oxygen, zinc enables your immune system to fight infection and selenium makes antioxidants that shield your cells from damage. The journey from cloud of dust to living planet has been a long one, but here we'll cover just how our lively planet evolved.

THE BIRTH OF OUR PLANET

How a cosmic cloud gave rise to life

The Solar System was born from a cloud of dust called a nebula. A shock wave, triggered by the death of a nearby star, caused that nebula to collapse. It tumbled in on itself, forming a hot, white ball of matter that became so dense that atoms at its core started to fuse. These nuclear reactions gave birth to the Sun. Around that young star, the rest of the cosmic dust from the nebula continued to swirl. It formed small clumps that started to grow by a process called accretion. These clumps became the planets and moons.

The formation of the planets took millions of years, and it wasn't peaceful. As Earth was beginning to take shape, large chunks of rock and ice were still hurtling through the Solar System. They would crash into Earth at random, melting the ground and sending violent shock waves into the mantle. The biggest of these collisions was with a planet-sized rock called Theia, which formed our Moon. Though devastating, that encounter played a vital role in the evolution of our planet. It stabilised Earth's rotation, helping to steady the climate, and it created the tides.

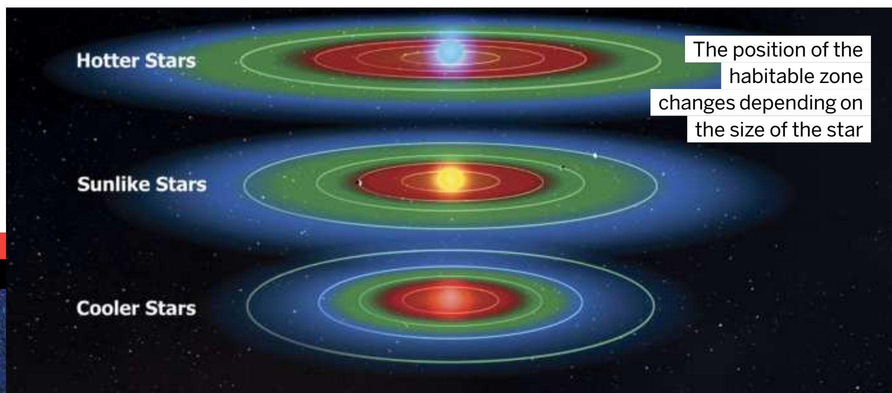
By the time Earth started to cool, most of its water had boiled away into space, and in the early years it didn't even have an atmosphere. Luckily, another planet was on hand to help. Jupiter sits just beyond the asteroid belt. Its massive gravitational influence slows passing rock fragments, pulling them into orbit around the Sun. It acts as our protector, but also as a slingshot, sending some of those asteroids and comets right into our path.

The projectiles Jupiter hurled at our planet in the early years of the Solar System were full of hydrogen and oxygen, the raw ingredients of water. These elements melted into the mantle and came out as rain when ancient volcanoes erupted, turning the bare rocks of early Earth into mineral-rich oceans.

Did you know?
Earth's crust is about 46 per cent oxygen

THE GOLDILOCKS ZONE

The chemical reactions that make life possible can only happen in liquid. Gas molecules are too far apart to interact, and solids can't move around enough to mix together. That's why water is essential. There's no other liquid in the universe that behaves quite like it. Made from one oxygen atom and two hydrogens, water molecules have a special chemistry. They can dissolve almost anything, allowing the chemicals of life to mix and react. The Goldilocks zone is the space around a star where water can exist in its liquid form: not too hot and not too cold, but just right for life to evolve.



The position of the habitable zone changes depending on the size of the star

WHERE THE MOON CAME FROM

Our closest celestial companion formed after a ball of rock named Theia hit Earth

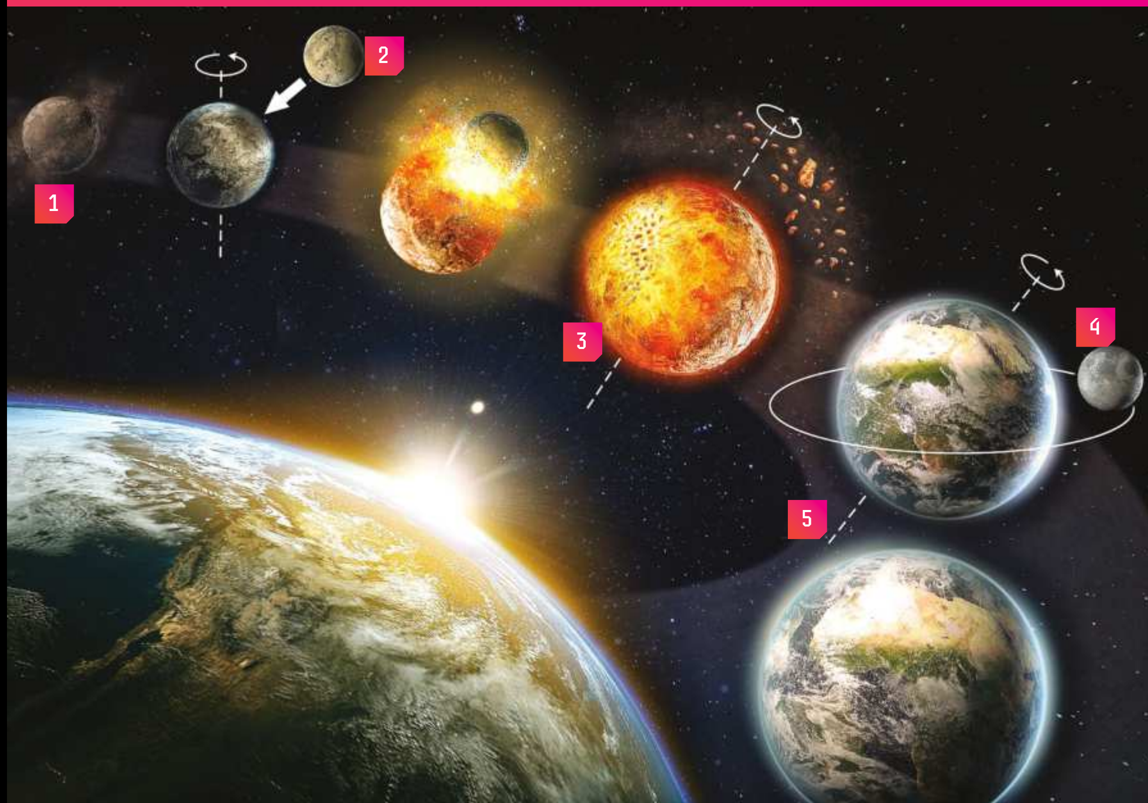
1 EARLY EARTH
The young Earth was a hot ball of rock and metal.

2 THEIA
4.5 billion years ago, a rock around half the size of Earth crashed directly into our young planet.

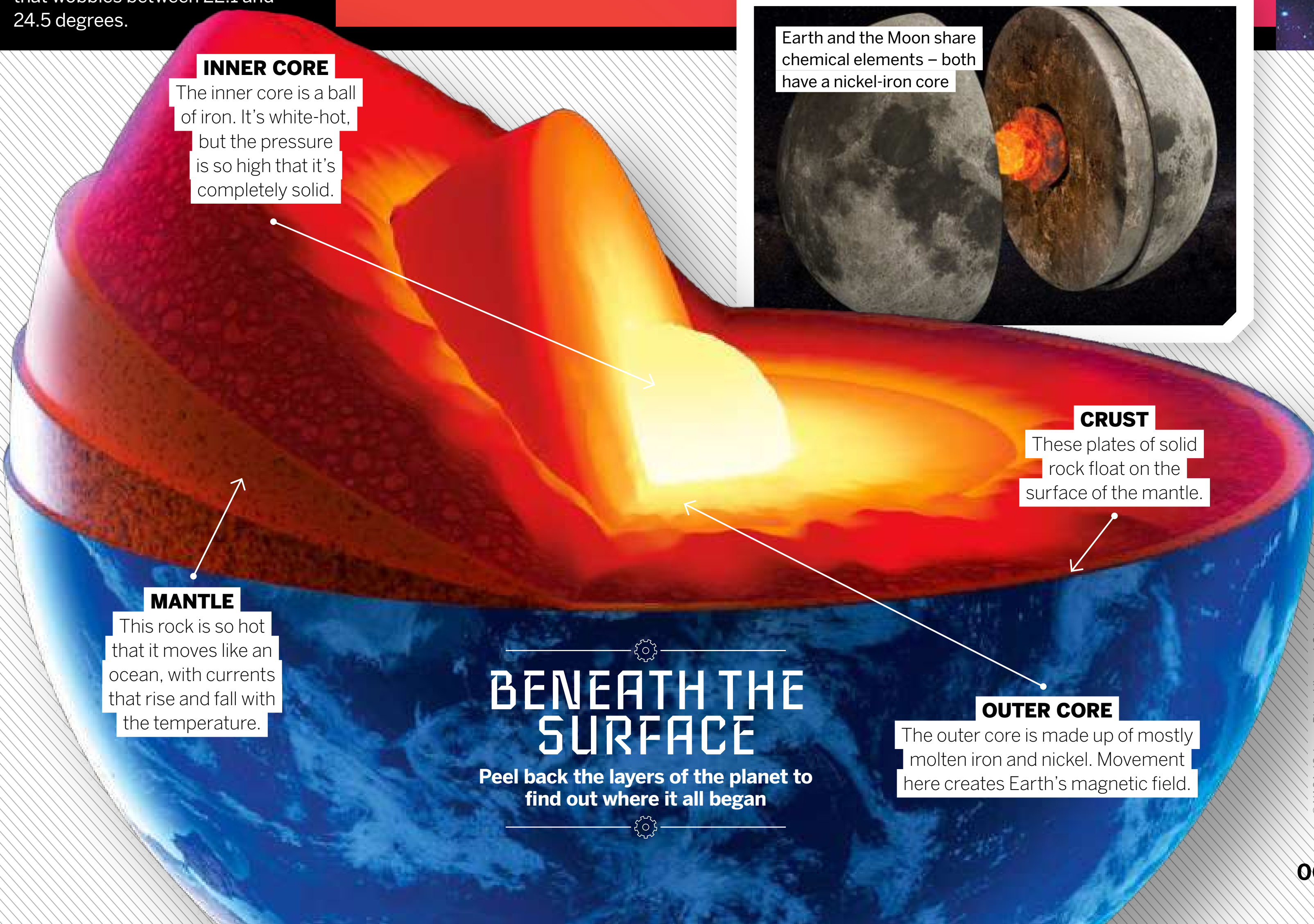
3 THE AFTERMATH
Theia and Earth combined with such force that the surface of the planet turned into rivers of magma.

4 THE MOON
The impact shot debris into orbit around Earth. The lightest elements boiled away, and the rest became the Moon.

5 TILTED AXIS
The collision knocked Earth sideways, toppling its axis into a tilt that wobbles between 22.1 and 24.5 degrees.



Earth and the Moon share chemical elements – both have a nickel-iron core



BENEATH THE SURFACE

Peel back the layers of the planet to find out where it all began

This NASA image shows hurricanes forming in the atmosphere over the Atlantic Ocean

EARTH'S EVOLVING CLIMATE

From hot to cold and back again

Just after the birth of the Solar System, in the Hadean Eon, the entire Earth was liquid, a hellscape of fire and lava. The planet was still being pummelled from all directions by meteor strikes. As Earth started to cool, a crust of solid rock began to appear on its surface, but at first it was very fragile. Repeated impacts and volcanic eruptions broke that crust into chunks called tectonic plates, which floated on the magma below.

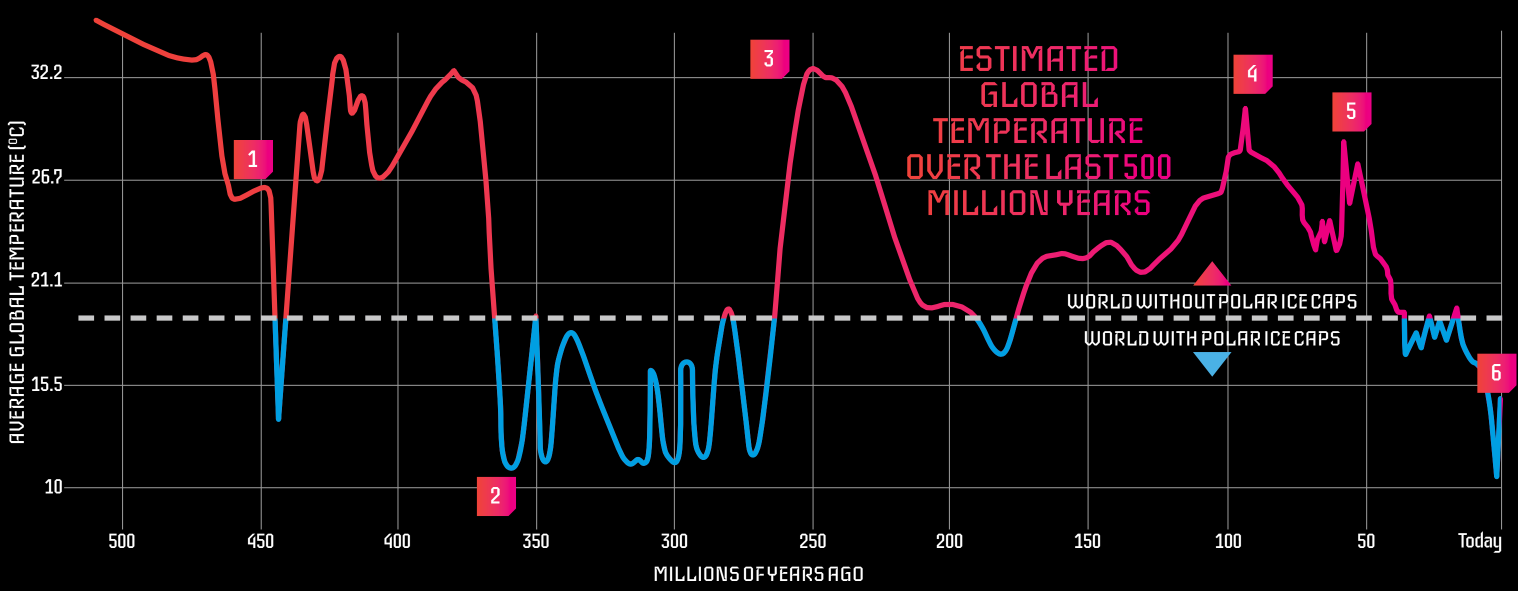
During the Archaean Eon, 4 to 2.6 billion years ago, the plates started moving, but when they collided, the heat of the mantle would break them apart. They had to stop, cool down and recover before they could start moving again. By the time this eon came to an end, tectonic plates had become more stable, and they had started to move constantly. Across history the plates have continually collided and separated, forming and reforming different patterns of continents and oceans.

These movements have had dramatic effects on Earth's climate. When continents break apart, the exposed rock absorbs carbon dioxide from the air, and global temperatures plummet. As volcanoes erupt, the greenhouse gases break free again and blow back into the atmosphere, trapping heat from the Sun. Events like these have triggered enormous freeze-thaw cycles in Earth's past.

Earth's position in space has influenced global climate too. After its collision with Theia, Earth's axis fell into a tilt, creating the seasons. That tilt has always been unstable, and so has the shape of Earth's orbit around the Sun. Our distance from the Sun changes on a 100,000-year cycle, tipping us in and out of ice ages. For the first part of Earth's existence, its climate was entirely dominated by these quirks of space and geology, but when life evolved everything changed.

"As Earth started to cool, a crust of solid rock began to appear"

During the Proterozoic Eon, evolution invented photosynthesis. The atmosphere filled with oxygen and gained a protective shield called the ozone, making it possible for living organisms to start terraforming the land. Our impact on the climate has been monumental, and today humanity is one of the most powerful forces of climate change.



1

450 million years ago

A thick, carbon dioxide atmosphere blanketed the entire Earth. The ocean was around 35 degrees Celsius.

2

360 million years ago

Plants covered the land, stripping carbon dioxide from the air. Temperatures dropped and the poles froze.

3

260 million years ago

Temperatures shot up again as volcanoes became more active, melting the ice and scorching the equator.

4

90 million years ago

Carbon dioxide levels skyrocketed, causing a period of warming called the Cretaceous Hot Greenhouse.

5

55 million years ago

The Paleocene-Eocene Thermal Maximum occurred – the world's most dramatic climate change event.

6

Today

Global average temperatures are rising sharply as greenhouse gases trap heat in the atmosphere.

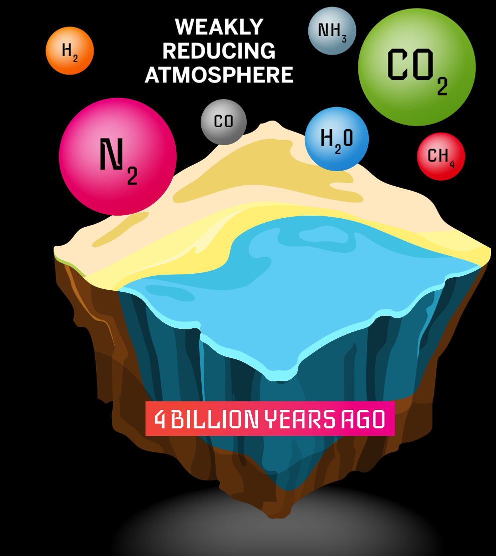
DID YOU KNOW? There is a greater than 95 per cent probability that human activity is driving the current warming of the planet

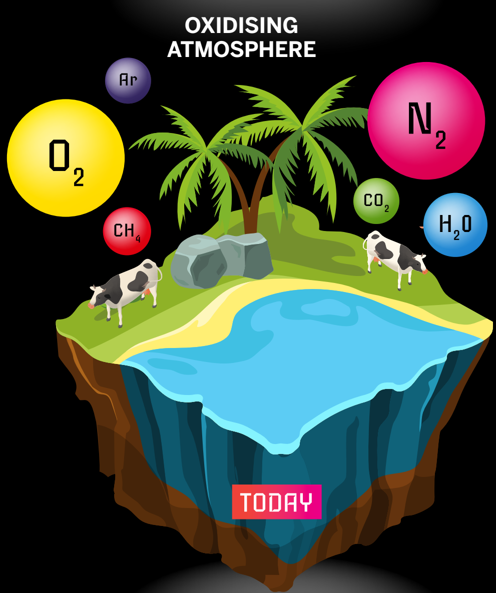
FORMATION OF THE ATMOSPHERE

Earth lost all its air almost as soon as it formed. Most of the gas was hydrogen and helium, and Earth's gravity simply wasn't strong enough to hold it down. This meant that in the earliest days, there was no air at all.

Earth's first atmosphere emerged from the belly of the planet. Gases bubbled up to the surface during violent volcanic eruptions, covering the ground in a hot blanket of carbon dioxide, nitrogen and water. Then came the rain. The water leaked out of the atmosphere in torrents that formed the first oceans, leaving nitrogen as the dominant atmospheric gas.

When life eventually evolved, the atmosphere changed again. Photosynthesising organisms pulled carbon dioxide from the air and split it apart, turning the carbon into food for their bodies and spitting the oxygen back out as waste. As that oxygen started to build up, ultraviolet light from the Sun shattered it into pieces. Those pieces recombined to make the ozone layer.





THE MAKING OF THE CONTINENTS

Plate tectonics shift the ground beneath our feet, changing the face of the Earth

1 RODINIA
1.3 TO 1 BILLION YEARS AGO

Fragments of Earth's crust pushed together to form the first supercontinent, lifeless rocks surrounded by a stormy ocean.

2 LAURENTIA
425 MILLION YEARS AGO

Heat tore Rodinia apart, releasing Laurentia, a vast land mass that would go on to become North America, Europe and Asia.

3 PANGAEA
237 MILLION YEARS AGO

The fragments of Rodinia rejoined to form Pangaea, upon which dinosaurs and mammals first evolved.

4 GONDWANA
152 MILLION YEARS AGO

Pangaea split apart into two great landmasses, with Laurasia to the north and Gondwana to the south.

5 MODERN EARTH
TODAY

Laurasia broke apart to form North America, Europe and Asia. Gondwana split into Africa, South America, India, Antarctica and Australasia.

6 FUTURE SUPERCONTINENTS
200 TO 300 MILLION YEARS FROM TODAY

The next supercontinent is due to form 200 or 300 million years from today, but exactly what it will look like is still something of an unknown. Scientists predict four possible scenarios: Novopangaea, Pangaea Proxima – or Ultima – Aurica and Amasia.

Novopangaea will form if the Atlantic Ocean continues to widen and the Pacific continues to close; this will cause the Americas to smash into Antarctica and Eurasia. Pangaea Proxima will form if the Atlantic starts to close, bringing the continents back together. Aurica will form if both the Atlantic and the Pacific Oceans close, sandwiching the Americas between Australasia and Antarctica and Eurasia. And Amasia (not shown) will form if the continents drift northwards and collide in the Arctic circle.

THE ORIGIN OF LIFE

One common ancestor gave rise to all things

Life on Earth is like nothing else in the universe – at least that we know of. Our planet is home to an estimated 8.7 billion different species. The smallest is the 400-nanometre microbe *Nanoarchaeum equitans*; the largest the six-mile honey fungus. Both of them, and everything in between, can trace their evolutionary ancestry back to a single species, known as the last universal common ancestor, or LUCA.

LUCA was a single cell with a little loop of genetic code carrying 100 essential genes, which it passed on to almost every organism alive today. A microbe, it lived 3.5 billion years ago in a hot volcanic vent deep beneath the surface of the ocean. There was no oxygen to breathe at the time, so LUCA survived on hydrogen, carbon dioxide and nitrogen. It made its energy using the natural gradient of ions that exists between hot thermal vent water and cold seawater.

> "We can trace evolutionary ancestry back to a single species"

LUCA gave rise to all three branches of the tree of life: the archaea, the bacteria and the eukarya. Each branch has left its mark on Earth, changing everything from the composition of the atmosphere to the shape of the land, the climate and the weather.

The archaea are the oldest and perhaps the strangest of Earth's organisms. They live in places no other life can survive, like boiling vents, bubbling acid and frozen ice.

The bacteria are the smallest and most prolific. These single cells have colonised almost every corner of the planet. Scientists estimate that there are 5 million trillion trillion of them alive today – that's 5,000,000,000,000,000,000,000,000,000,000!


For millions of years, most of Earth's life was underwater

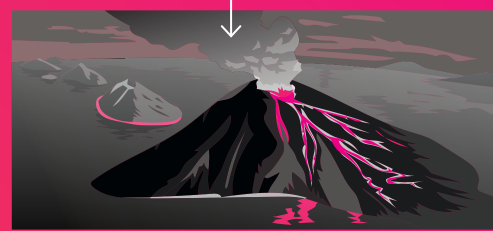

Today the vast majority of Earth's animals live on land

PRIMORDIAL SOUP THEORY

Could life really have started in a warm little pond?

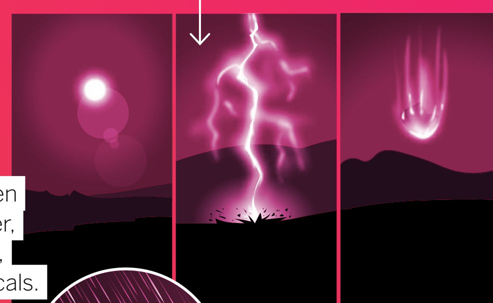
VOLCANIC ORIGINS

Earth's early atmosphere was a hot mixture of carbon, nitrogen and hydrogen-containing chemicals like carbon dioxide, methane and ammonia. There was no oxygen, and violent volcanic eruptions threw dust and ash into the air, creating rocky islands in the ocean.



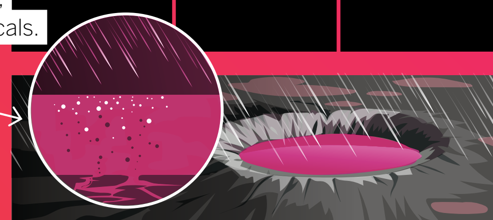
A SPARK

The heat of the Sun, the impact of asteroids and the arcing electricity of lightning acted as catalysts. They triggered the production of hydrogen cyanide, which dissolved into pools of water on the ground.



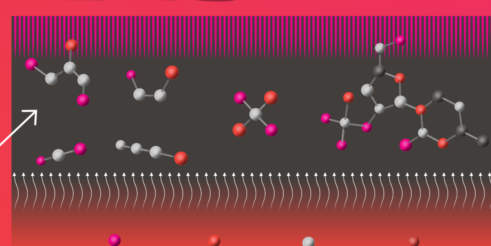
HEAT AND LIGHT

Under the hot ultraviolet light of the Sun, hydrogen cyanide reacted with other chemicals in the water, forming cyanide salts. As the water evaporated, these salts became a concentrated crust of chemicals.



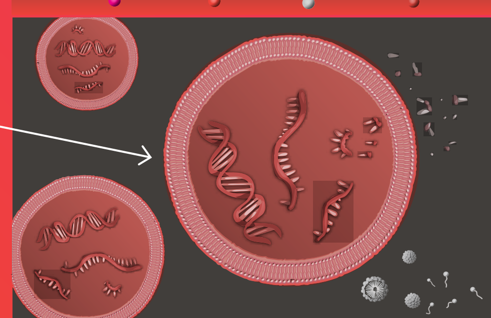
CREATING CHEMISTRY

In the presence of these cyanide chemicals and phosphates, the other hydrogen, carbon and nitrogen-containing compounds in the water reacted together. They formed nucleotides, the building blocks of genetic material.



PROTOCELLS

Fatty acids in the water closed around these early strands of genetic code, forming tiny cell-like bubbles. More fats joined the bubbles, allowing them to grow and divide. The new bubbles took pieces of genetic code with them.



The eukarya are the youngest and most diverse of Earth's creatures. They include almost all life you see around you, from plants and animals to fungi, yeast and amoebae. LUCA was the shared ancestor of everything, but it wasn't Earth's first life form. Fossil evidence of life on Earth dates back as far as 3.7 billion years, and scientists believe that the first living organisms emerged even earlier.

The very first living organism had to come from something not living, a process that scientists call abiogenesis. But how that happened is still a mystery. What we do know is that life began when Earth was in its Hadean Eon, a time when rust was raining down on the planet. Violent iron hailstorms tore through the atmosphere, reacting with water to form red dust. This reaction produced hydrogen as a waste product, and that hydrogen was key to the formation of life. It had the power to reduce other chemicals, adding electrons and stripping away oxygen. These reduction reactions created the three building blocks of life: nucleic acids, fatty acids and amino acids.

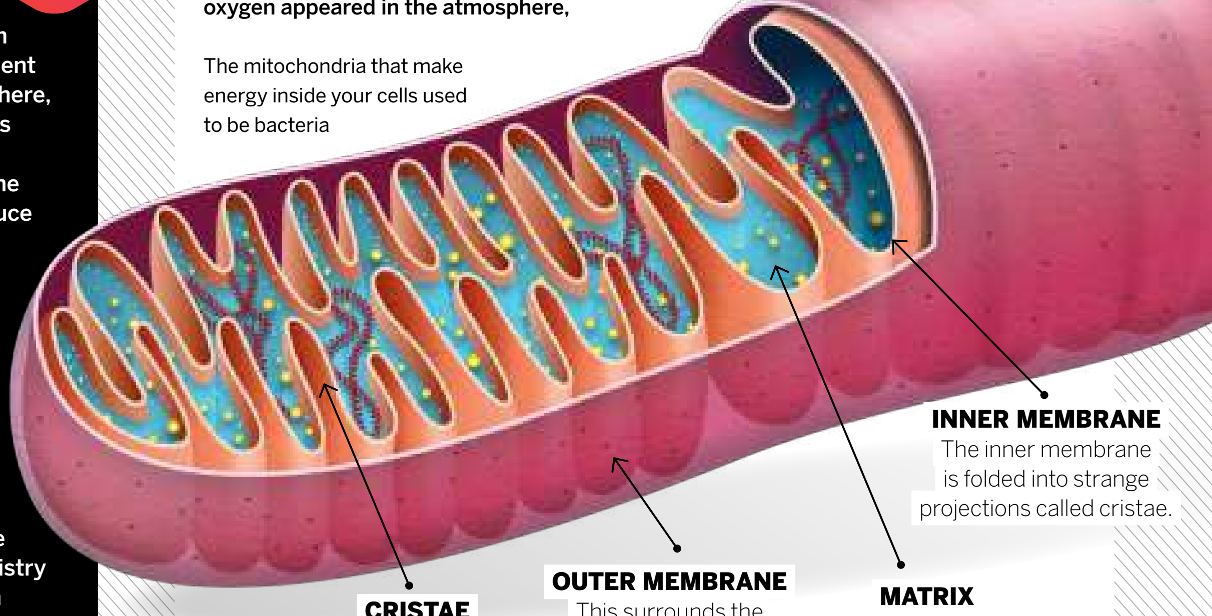
Alone these building blocks are not alive, but when they combine, something incredible happens. Strings of nucleic acids form RNA and DNA, the carrier molecules of genetic code. Strings of amino acids form proteins, the molecular machines that drive the chemistry of living organisms. And fatty acids form bubbles called membranes, which separate life from the rest of the world. Scientists disagree about which of these molecules came first, but it was the combination of the three that made life on Earth possible.

Did you know?
Stromatolite fossils are the oldest found

WHERE DID OUR CELLS COME FROM?

One of the biggest events in the history of evolution was the development of mitochondria, the energy factories of all complex cells. Scientists think that they only evolved once, an event that completely changed the course of evolution. For billions of years, life was just single cells. It was impossible to make enough energy to form multicellular organisms like plants and animals. When oxygen appeared in the atmosphere, some cells learned how to use the new gas. In a chance event, one of these oxygen-breathing cells got inside a larger cell and started dividing. The two types of cell started to work together to make more energy than ever before. Over time, their relationship became permanent, and the oxygen-breathing cells became the mitochondria.

The mitochondria that make energy inside your cells used to be bacteria



THE EVOLUTION OF LIFE ON EARTH

3.8 BILLION YEARS AGO
The very first microbes appeared: simple organisms with just a single cell.

3.5 BILLION YEARS AGO
LUCA emerged – the organism from which every creature alive on Earth today has evolved.

2.4 BILLION YEARS AGO
Runaway photosynthesis caused the Great Oxidation Event. A mass extinction began as ancient organisms struggled to cope with rising oxygen.

1.7 BILLION YEARS AGO
Organisms with more than one cell began to emerge. First sponges, then fungi and corals.

500 MILLION YEARS AGO
Under the cover of the newly formed ozone layer, the Cambrian explosion began, and thousands of animal species evolved.

367 MILLION YEARS AGO
The first four-legged animals, called tetrapods, started to evolve, making way for the colonisation of land.

225 MILLION YEARS AGO
The very first dinosaur appeared, marking the beginning of a multimillion-year planetary takeover.

178 MILLION YEARS AGO
The very first mammals started to emerge, but dinosaurs put the brakes on their evolution.

66 MILLION YEARS AGO
An enormous asteroid triggered the Cretaceous-Paleogene mass extinction event, wiping out non-avian dinosaurs.

50 MILLION YEARS AGO
Mammals filled the gaps left by the dead dinosaurs, becoming the most dominant group of animals on the planet.

HOW SMART IS A DOLPHIN?

These marine mammals are some of the cleverest creatures in the ocean

WORDS SCOTT DUTFIELD

Dolphins are commonly credited as being one of nature's smartest animals, often being compared to the heightened intellect of great apes or humans. Intelligence in the animal kingdom isn't measured solely on the size of the brain, but by how it compares to the overall mass of the animal. Neuroscientist Harry J. Jerison proposed in a 1973 paper that the ratio of body mass, actual brain size and expected brain size are related to an animal's cognitive ability. He invented a way to accurately represent the ratio between an animal's brain and body through a series of calculations.

These calculations are now called the encephalisation quotient (EQ), taking the volume of the brain to the volume of its expected body size into account. An EQ score compares one species' ratio to other similarly sized animals. For example, humans have the highest EQ of any primate, scoring between 7.4 and 7.8. This means that a human brain is seven to eight times bigger than an average mammal of comparable size. The EQ score of a bottlenose dolphin is around 5.2.

Did you know?

Dolphins can recognise themselves in a mirror

A pod of long-beaked common dolphins hunting a school of fish

Other than the mass of a dolphin's brain, their cellular makeup also gives them an intellectual leg up on other animals. Von Economo neurons (VEN), also known as spindle neurons, are complex cells deep within the brain and have been associated with assisting in social awareness and interoception – the sense of what's going on inside your body. Some scientists have speculated that the presence of these types of neurons is related to individual differences in general intelligence.

Previously it was thought that great apes and humans were the only species to have these smart cells. However, some marine mammals, including some species of dolphins, also possess spindle neurons.

Along with their big brains, dolphins are also capable of complex social interactions and are known to create tight-knit communities which help one another survive. A group of dolphins, known as a pod, works together while hunting fish. In a coordinated assault, dolphins encircle a school of fish with ever-decreasing circles of bubbles, compacting and trapping the school and making individual fish much easier for the dolphins to pick off. Dolphins have also been known to collect heavy, fish-bearing conch shells, taking them to the surface and shaking the fish out for a quick bite.

HALF ASLEEP

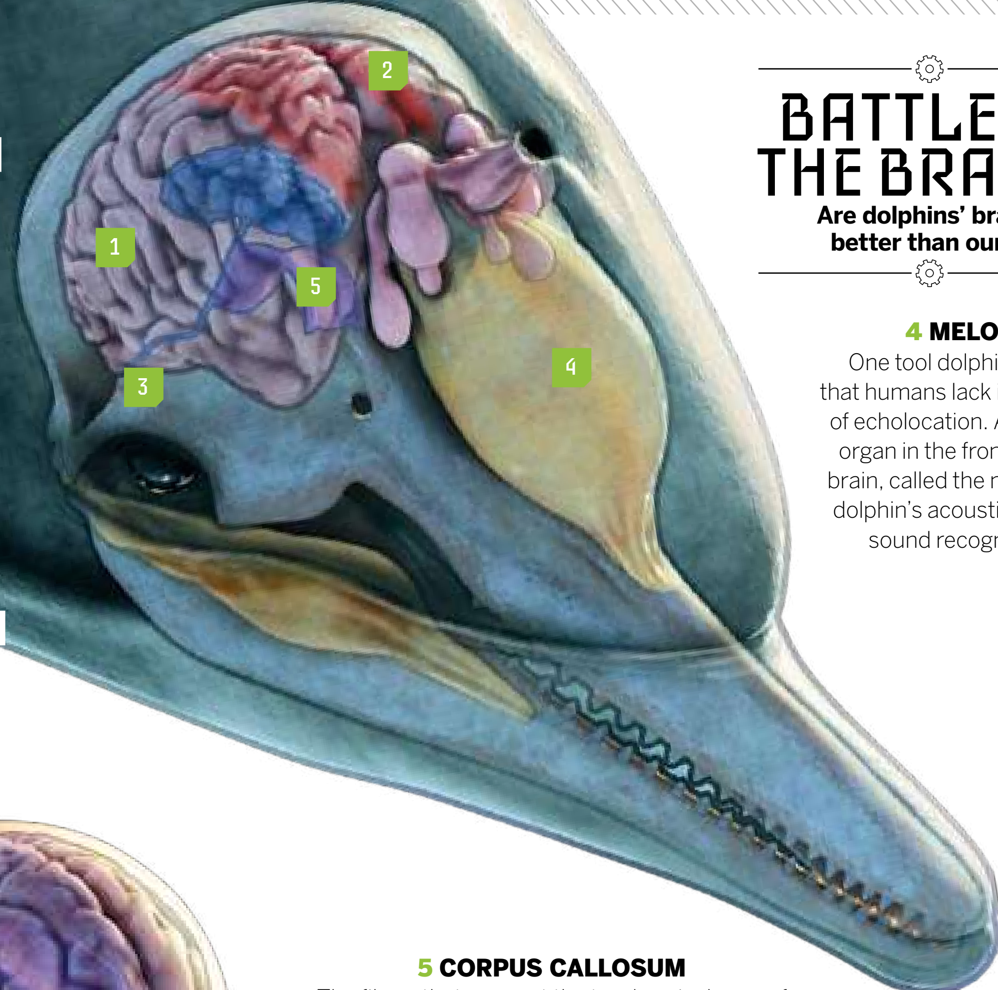
Spending your entire life living in water as a mammal makes sleeping without drowning a difficult feat. But dolphins have evolved an ingenious way to remain fully rested without filling their lungs with water. Rather than slipping into unconsciousness, dolphins can temporarily 'turn off' one side of their brain to rest, closing the opposite eye. The active hemisphere of the brain will remain conscious to ensure the dolphin rises to the surface to take a breath. Like humans, dolphins sleep at night, but only allocate around two hours of their time resting each hemisphere.

A dolphin resting on the surface of the water in Australia

DID YOU KNOW? After humans, capuchin monkeys have the second-highest EQ score of any primate, at 4.8

BATTLE OF THE BRAINS

Are dolphins' brains better than ours?



1 CEREBRAL CORTEX

The outermost part of the brain is associated with the highest mental abilities of a human or animal. Dolphins have 40 per cent more cerebral cortex than humans.

2 VISUAL ORGANS

The visual regions of a dolphin's brain are situated more closely to the auditory sections. This allows them to translate sound into images and vice versa.

3 AUDITORY NERVE

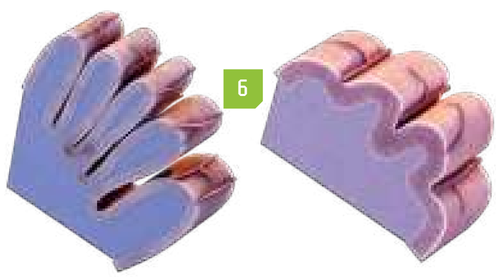
The auditory nerve sends information about sounds from the outside world to the brain for translation. In dolphins this nerve is twice the diameter of a human nerve, which makes them able to rapidly process sound.

4 MELON

One tool dolphins have that humans lack is their use of echolocation. A sensory organ in the front of their brain, called the melon, is a dolphin's acoustic lens for sound recognition.

5 CORPUS CALLOSUM

The fibres that connect the two hemispheres of the brain are collectively called the corpus callosum. This bridge of fibres is four times bigger in humans than dolphins due to dolphins' alternating brain activity while sleeping.



6 BRAIN FOLDS

Generally, a larger number of folds in a brain indicates higher intelligence. This is because the surface area of the brain is higher. An unfolded dolphin brain is around the size of six magazine pages; a human brain is only around four pages.

DOLPHIN SUPERSTARS

The largest bottlenose dolphins in the world live in the Moray Firth inlet in Scotland. They adapted to survive the cold, treacherous waters of the North Sea in many ways, from packing on insulating layers of blubber to understanding tidal fluctuations to find food. These amazing dolphins are also experts in saving energy and have taught themselves a neat trick: using just their tails to keep them in position, they swim against the current waiting for salmon on the incoming tide and gulp this tasty meal down headfirst. Just like us, these bottlenose dolphins – and some whale species – have special cells in their brains called spindle neurons, associated with advanced abilities like remembering, communicating, tool use and problem-solving. For more amazing dolphin facts, visit whales.org to find out how to help protect them. You can even adopt a Moray Firth dolphin and learn more about their fascinating lives.

Adopt a dolphin today with WDC and help protect Scotland's Moray Firth dolphins


A common cuckoo (*Cuculus canorus*)

Did you know?
Around 40 per cent of cuckoos are brood parasites

HOW CUCKOOS TRICK OTHER BIRDS

Discover the cunning parenting of the cuckoo

WORDS **AILSA HARVEY**

Cuckoos are masters of deception. When it comes to raising young, they don't expend the energy building a nest, protecting eggs or feeding offspring. Instead the female passes these roles on to unsuspecting victims. These birds are brood parasites – they don't raise their own young. They lay their eggs in the nests of other species, tricking them into thinking the eggs are their own. Some of their main targets include dunnocks, meadow pipits and reed warblers.

To pull off this cunning stunt, the female cuckoo watches over her chosen nest to observe feeding times. When the host parent has left in search of food, the cuckoo will quickly lay an egg among those already in the nest. Sometimes she will even destroy and remove one of the host's eggs to make room for her own.

Cuckoos are birds in the Cuculidae family. They are medium-sized with long tails, and often have grey or brown backs. When they hatch and begin to grow in a host's nest, the difference in species can be obvious to an onlooker. Often the cuckoo is twice the size of its foster parent, but still continues to receive food from them.

The cuckoo imposter is usually the only hatchling that the host parent has to care for. This is because when the cuckoo hatches after around 11 days, it gets rid of all the other eggs in the nest. It will lift each egg onto its back before throwing them one by one over the edge of the nest. Even then, the non-biological parent will continue to treat the cuckoo as one of its own. After 20 days the cuckoo will leave the nest, but still receives food from its host.

IS IT FOOLPROOF?

Although the cuckoo's trick has a high success rate, some hosts are harder to fool. If a female cuckoo is spotted laying her eggs in the wrong nest, or the bird becomes aware that one egg is different, cuckoo eggs can be attacked. The host pierces the shell of the imposter egg and throws it out of the nest. In other instances, nests are abandoned and the cuckoo isn't fed.

Cuckoos sometimes lay their eggs outside of a nest. If an egg looks similar to the host's, this misplaced egg can be retrieved and placed into the nest. The likelihood that a chick will be rejected depends on the cost of raising the cuckoo. An example of this is when the cuckoo is much larger than its unsuspecting new parents. Feeding the cuckoo will use up much more of the host birds' energy.


A marsh warbler feeding a much larger cuckoo chick


Cuckoo chicks can throw eggs out of nests by carrying them on their back

EGG MIMICRY


The larger cuckoo egg looks similar to the marsh warbler's

To intrude successfully, cuckoos have evolved disguises such as egg colouration. Cuckoos have evolved to produce eggs similar in colour to their main hosts'. This reduces the chances of eggs being attacked. Female cuckoos have been known to distract host birds after laying their eggs by making a noise similar to the Eurasian sparrowhawk, scaring birds away from returning to the nest and allowing time for the cuckoo to make its escape unspotted.

HOW FIRESTORMS FORM

Onlookers witnessed a fire tornado rising from the flames of the Pine Gulch Fire in August 2020 in Colorado

What do you get when you cross a fire with a tornado?

WORDS **CHARLOTTE HARTLEY**

This apocalyptic-sounding phenomenon occurs when a fire grows large and angry enough to sustain its own weather system. Fierce heat, mixed with turbulent whirlwinds, creates a tornado-like vortex. It sucks ash, embers and flammable gases up into the air, forming a swirling tower of flame called a fire whirl, but also frequently referred to as a fire tornado. These are not considered true tornadoes, however. Unlike a tornado, the vortex of a fire whirl rarely extends all the way from the ground to the clouds, and they form differently.

The most impressive fire tornadoes are forged from wildfires, where they typically reach between 10 and 50 metres in height. Some are born in the plume of a volcanic eruption. Fire whirls are usually transient, fluttering into existence for only a few short minutes before swiftly dying. There are exceptions though: in the Carr Fire of California in 2018, a monstrous three-mile-tall 'firenado' blazed for almost an hour.

Unsurprisingly, these fiery spectacles can be a force of destruction. Fire tornadoes can blaze through natural forests and human-made settlements alike. Sometimes the intense winds lift up burning materials and spit them out elsewhere. This is called 'spotting', and it helps wildfires spread.

Fire tornado formation is relatively rare; it relies on a precise balance of extreme temperatures and rapidly changing wind speed or direction. But as a warming climate and poor fire management practices increase the frequency of large wildfires, these conditions could be met more easily in future.

Did you know?
These tornados are usually two to ten metres in height

A fire tornado blazed through the town of Peshtigo in 1871, destroying everything in its path

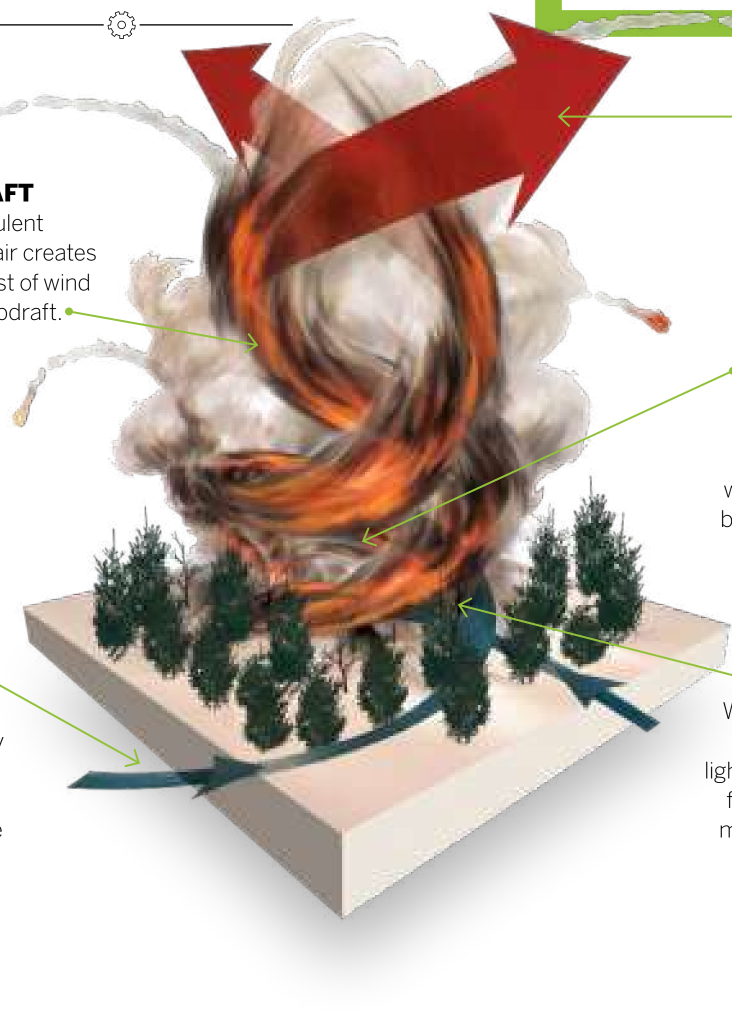
THE PESHTIGO FIRESTORM

On 8 October 1871, a vast inferno swept through the community of Peshtigo in Wisconsin. The fire burned around 1,200,000 acres of land and killed between 1,500 and 2,500 people. But despite it being America's deadliest wildfire in recorded history, many people have never heard of the Peshtigo Fire. It has been largely overshadowed by the more famous Great Chicago Fire, which occurred on the same day.

An unusually dry summer season had triggered a few smaller and manageable wildfires in the area. But then strong winds from the west fanned their flames, blowing the fires out of control into a devastatingly destructive firestorm.

HOW DOES A FIRE WHIRL FORM?

These fiery whirlwinds require a precise combination of weather conditions



UPDRAFT
The turbulent movement of air creates a powerful gust of wind called an updraft.

VACUUM
Rising hot air leaves an empty space called a vacuum. Air surrounding the fire rushes in to fill the void.

FIRE WHIRL
Embers and ash from the wildfire get caught in the wind, swirling the fire up into a tornado-like whirl.

HEAT RISES
Fire heats the air around it. Gases expand as they warm, so the hot air becomes lighter and floats upwards.

WILDFIRE
Wildfires can occur naturally due to lightning strikes or lava flows. But the vast majority are caused unintentionally by people.

10 DEADLY VOLCANIC ERUPTIONS

How Earth's fiery outbursts remind us of our planet's power and unpredictability

WORDS AILSA HARVEY

As a species that has evolved to suit conditions on the surface of Earth, humans don't fare well when the planet spills out its innards. Searing magma from the flowing mantle below the crust can push through ruptures in the outer layer. Local scientists can sometimes predict these explosions by monitoring volcanoes' behaviour or documenting those that are particularly volatile. Active volcanoes are often classed as 'dangerous' and extinct volcanoes as 'safe', but what happens when one dismissed as dormant has a change of heart? Throughout history, the volcanoes that have claimed the most lives held an element of mystery and surprise, with incredible and terrifying power lurking within. These are the world's deadliest eruptions.

DID YOU KNOW? During the 1783 to 1784 eruption of Mount Laki in Iceland, lava spewed from 135 fissures

Mount Vesuvius is still active and has erupted over 50 times

1

DEATH TOLL 10,000+

MOUNT KELUD'S LETHAL LEGACY

EAST JAVA, INDONESIA

One of Mount Kelud's most significant outbursts occurred over five centuries ago, in 1586. Though hosting a full crater lake, the volcano was ready to blow, with lethal power. The hot mudflows triggered by the eruption crushed and buried anything in their path, killing over 10,000. Following the eruption – the largest ever recorded from the volcano – no activity was recorded for the next 75 years.

Another deadly eruption occurred on 19 May 1919, releasing a relentless mudflow with temperatures around 1,000 degrees Celsius over East Java, killing over 5,000 people. Also known as a lahar, it moved at 37 miles per hour and was triggered by the eruption, which displaced the crater lake containing 40 million cubic metres of water at the summit. As the scalding water flowed down the volcano it combined with rock and mud to form a deadly cascade that swept through 100 villages.

The devastation of 1919 led to engineering work to build a tunnel into the volcano. This lowered the lake's water level, with the water draining into the tunnel on the crater's southwestern side. In later eruptions, this prevented such large volumes spilling out from the top.

This volcanic rock was transported over 25 miles during the 1919 eruption

2

DEATH TOLL 16,000

VESUVIUS AND THE LOST CITIES

CAMPANIA, ITALY

Mount Vesuvius spent centuries being peacefully still before exploding with vigour in 79 CE. Towering 1,280 metres above the southern Italian cities of Pompeii and Herculaneum, around midday on 24 August, Vesuvius showered these communities in hot rock and ash. Studies of the bones of Herculaneum residents suggest that the liquid in many of the victims' bodies was boiled instantly upon contact with the volcano's contents. For those in Pompeii who hadn't fled by the next morning, a second release of gas and ash from the volcano swept into the city to claim their final breaths. Following this, a large flooding of volcanic mud and debris buried both Roman cities, only for them to be rediscovered during excavations throughout the 1900s.

Lightning can form from the electrical discharge of an eruption

3 MALARIA OUTBREAK OF SANTA MARÍA

After at least 500 years of inactivity, Santa María volcano in Guatemala exploded in October 1902, claiming the lives of more than 6,000 people. Additionally, the release of ash was fatal to local birds, allowing their mosquito prey to thrive. This led to many more people dying indirectly from malaria outbreaks.

4 ICELAND'S FAMINE

Starting on 8 June 1783, 3.7 quadrillion gallons of lava erupted from Mount Laki, Iceland, travelling over 600 square miles. Around 9,000 people died, and those who survived faced the resulting famine. Surrounding farms were burned or poisoned, killing cattle and crops along with 25 per cent of Iceland's population.

5 TSUNAMI SURGE

The force released from Mount Unzen in 1792 was the beginning of a domino effect and Japan's most devastating volcanic event. As the eastern side of the volcano collapsed, a landslide travelled across Shimabara city and into the surrounding sea, triggering a tsunami. Together the eruption and tsunami caused around 15,000 deaths.

6 TOBA'S ACID RAIN

Around 75,000 years ago, Toba volcano in Indonesia caused sulphuric acid rain to fall at both poles after injecting masses of sulphur dioxide into the atmosphere. Some studies suggest the change in climate allowed only 10,000 humans to survive.

7 PINATUBO'S WEIGHT

When a typhoon followed the eruption of Mount Pinatubo in 1991, the roofs of surviving buildings fell and crushed their inhabitants. This is because the rain saturated the fallen ash, increasing its weight and causing roofs to cave in.

DEATH TOLL
23,000

8 NEVADO DEL RUIZ: A GLACIAL BURN

CENTRAL ANDES, COLUMBIA

You wouldn't expect an icy mountain to burn you alive, but Colombia's Nevado del Ruiz volcano did just that. On 13 November 1985, an explosion from its large Arenas crater transformed the summit's snow and glaciers into the start of a fatal mudflow. After monitoring the early activity – from its first stir until the evening – scientists said the event posed no danger to nearby residents. This meant that many who lived beneath the mountain in the city of Armero were asleep when the mud began to race down the slopes towards them. This was the first major eruption of the 5,321-metre volcano in around 150 years.

Nevado del Ruiz is situated in central Columbia

Mount Laki can be found in Vatnajökull National Park, Iceland

DID YOU KNOW? On 27 August 1883, Krakatoa's explosions were heard 1,930 miles away in Perth, Australia

DEATH TOLL
36,000+

9

CHAOS ON KRAKATOA

How a natural disaster in 1883 shaped the landscape on the Indonesian island of Krakatoa

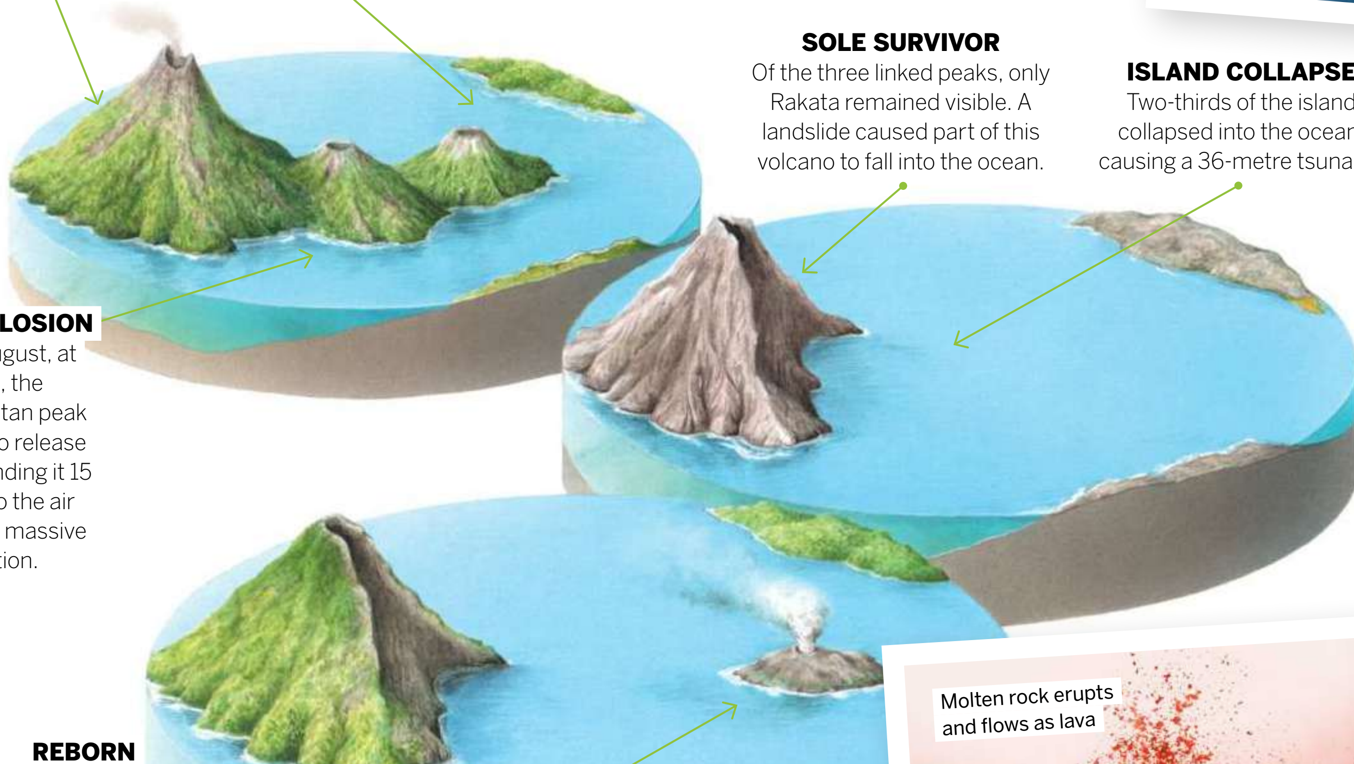
SUNDA STRAIT, INDONESIA

BEFORE 1883
Krakatoa originally had three peaks. It had not experienced an eruption for at least two centuries.

WARNING SIGNS
From May until August, ships that sailed past the volcano – which lies between Java and Sumatra – reported seeing ash and dust.

SOLE SURVIVOR
Of the three linked peaks, only Rakata remained visible. A landslide caused part of this volcano to fall into the ocean.

ISLAND COLLAPSE
Two-thirds of the island collapsed into the ocean, causing a 36-metre tsunami.



THE EXPLOSION
On 26 August, at 13:00, the Perboewatan peak was first to release debris, sending it 15 miles into the air above in a massive eruption.

REBORN
After the island collapsed in on itself, a caldera formed underwater. Layers of ejected lava built up from its vents until a new volcano emerged at the ocean's surface in 1927. This was named Anak Krakatoa, meaning 'Child of Krakatoa'.

10

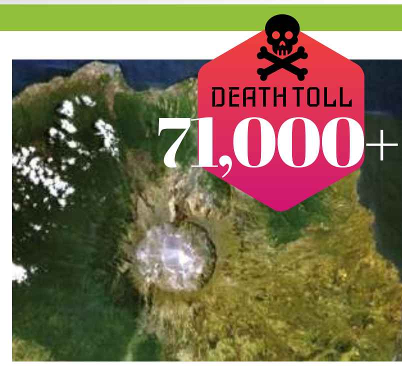
MOUNT TAMBORA: THE DEADLIEST OF THEM ALL

SUMBAWA ISLAND, INDONESIA

Of all recorded volcanic eruptions, Mount Tambora of Indonesia takes the title of deadliest. 10,000 people on the island of Sumbawa died instantly in the 1815 blast, but the greater environmental impact caused more than 71,000 deaths. Tambora's gigantic eruption was so powerful that soldiers hundreds of miles away mistook its sound for cannon fire, and lava flowed continuously from the volcanic site for two hours.

As the hot lava met the ocean it reacted with the cold water to send ash high into the air, spreading it even further. For hundreds of miles dark, ash-filled skies and falling remnants prevented crops from growing and spread disease, while acid particles, spread by Tambora's sulphurous waste, lowered temperatures across the Northern Hemisphere. Crops froze, contributing to starvation, and many died due to the colder, harsher climates the eruption caused.

DEATH TOLL
71,000+



Mount Tambora has a caldera nearly four miles wide

HOW BEES MAKE HONEY

This process turns nectar into a sticky, sweet substance

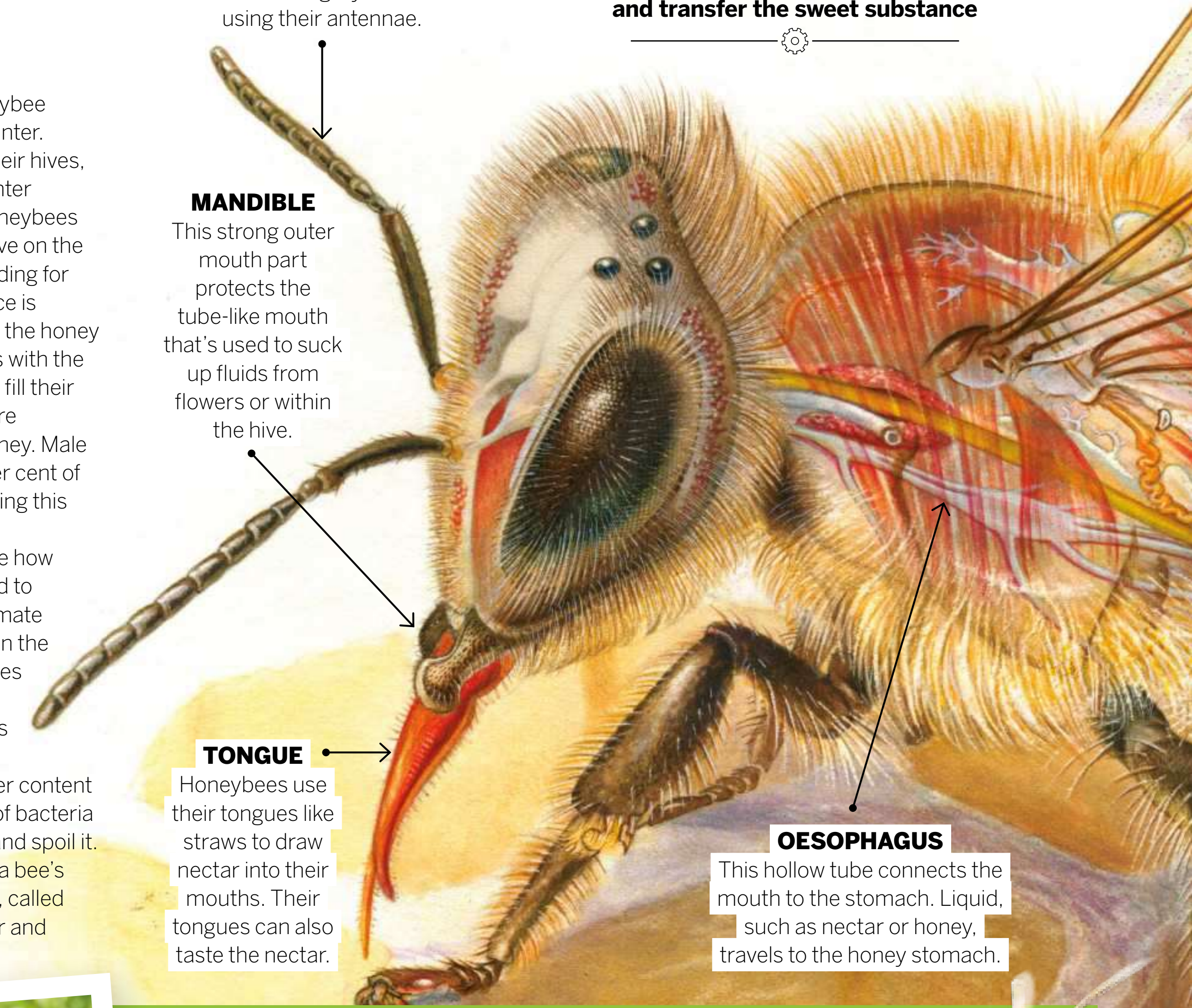
WORDS **AILSA HARVEY**

Unlike many other bees, honeybee species don't hibernate in winter. Instead they stay active in their hives, but what's their secret to winter survival? During the coldest months, honeybees cluster together to keep warm and survive on the sweet substance that they've been hoarding for weeks in advance. That special substance is honey. All the bees in a hive benefit from the honey haul, but the job of honey production lies with the female worker bees. These forager bees fill their stomachs with nectar from flowers before returning to the hive to convert it into honey. Male honeybees, which make up about ten per cent of the hive population, spend their lives eating this honey before leaving the hive to mate.

There are many factors that determine how much honey a single bee colony will need to produce for winter. It depends on the climate where the bees live, how much ventilation the hive has, and the number and type of bees in the hive. Honeybees will continue to make honey until every cell in their hive is full, and once produced, honey is very long-lasting. Honeybees reduce the water content in honey, which greatly limits the ability of bacteria and other microorganisms to grow in it and spoil it. Before nectar becomes honey, it enters a bee's stomach. An enzyme in bees' stomachs, called glucose oxidase, breaks down the nectar and helps produce the honey.

NECTAR COLLECTORS

A honeybee's anatomy is adapted to collect and transfer the sweet substance



Beekeepers often harvest honey three times in one season

SHOULD WE HARVEST HONEY?

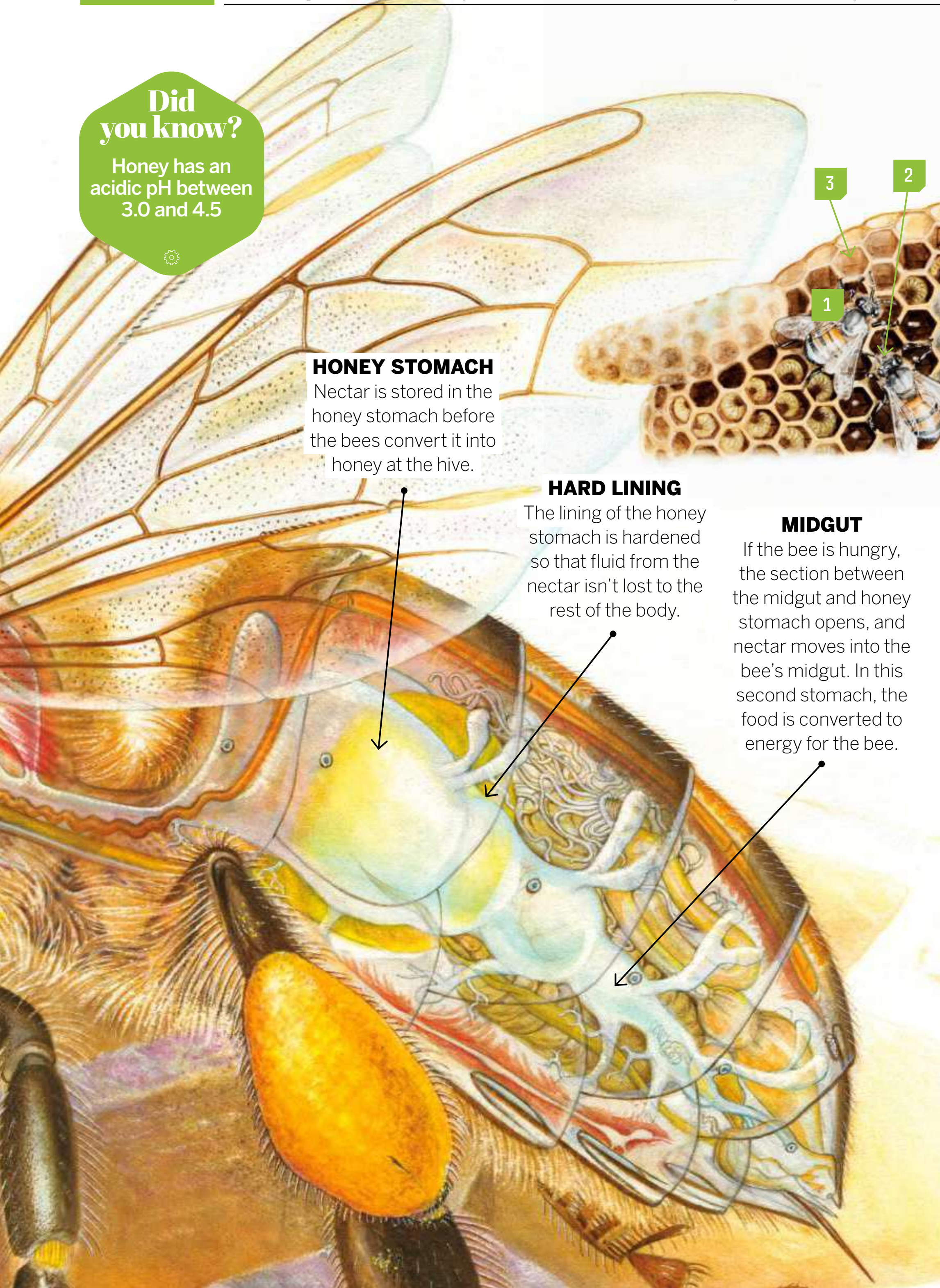
Beekeepers harvest and sell the honey made by bees in artificial hives. Bees can produce more honey than they need to sustain their colony over the winter period, so many beekeepers believe that using the excess for human benefit causes little harm to the bees' welfare. Others claim that the bees are overworked as they have to make up extra volumes of honey to replace what's taken.

As bees search for nectar, hairs on their bodies brush flowers and pick up pollen. When flying from flower to flower, the bees transfer the pollen and help flower species to reproduce. This is why it's beneficial to protect bee populations. Harvesting honeybee produce increases the number of bees in an area, but because these domesticated bees compete with other native bee species, flower resources become limited and can eventually cause other bee species to die out. Different bee species target specific flowers, and so a balance of honeybees and other bee species is essential in the long-term survival of plant and insect species.

DID YOU KNOW? An average honeybee can produce about 1/12th of a teaspoon of honey in its lifetime

Did you know?

Honey has an acidic pH between 3.0 and 4.5



HONEY STOMACH
Nectar is stored in the honey stomach before the bees convert it into honey at the hive.

HARD LINING
The lining of the honey stomach is hardened so that fluid from the nectar isn't lost to the rest of the body.

MIDGUT
If the bee is hungry, the section between the midgut and honey stomach opens, and nectar moves into the bee's midgut. In this second stomach, the food is converted to energy for the bee.

FLOWER SEARCHERS
When a honeybee lands on a flower, the feet are first to check for nectar. They can detect sweetness through their feet, which can determine whether they use their tongues.

IN-HIVE PRODUCTION

How is honey perfected and stored inside beehives?

1 ENTERING THE HIVE
A bee may need to visit over 1,000 flowers before its honey stomach is completely full. When this is achieved it will return to the hive to begin the honey-making process.

2 TEAMWORK
The bee with the nectar regurgitates it. The nectar is passed from mouth to mouth between the hive's bees to reduce its moisture content. Each bee chews the nectar for about half an hour.

3 OPTIONAL PREPARATION
Sometimes the nectar can be placed into an empty cell before it's passed to another bee. A hive can be 32.5 degrees Celsius, helping some of the moisture evaporate from the nectar while it's stored.

4 HONEY-FILLED CELL
When the nectar's moisture content is reduced from 70 per cent to 20 per cent, it becomes honey. The honey is stored in cells within the hive until it's needed.

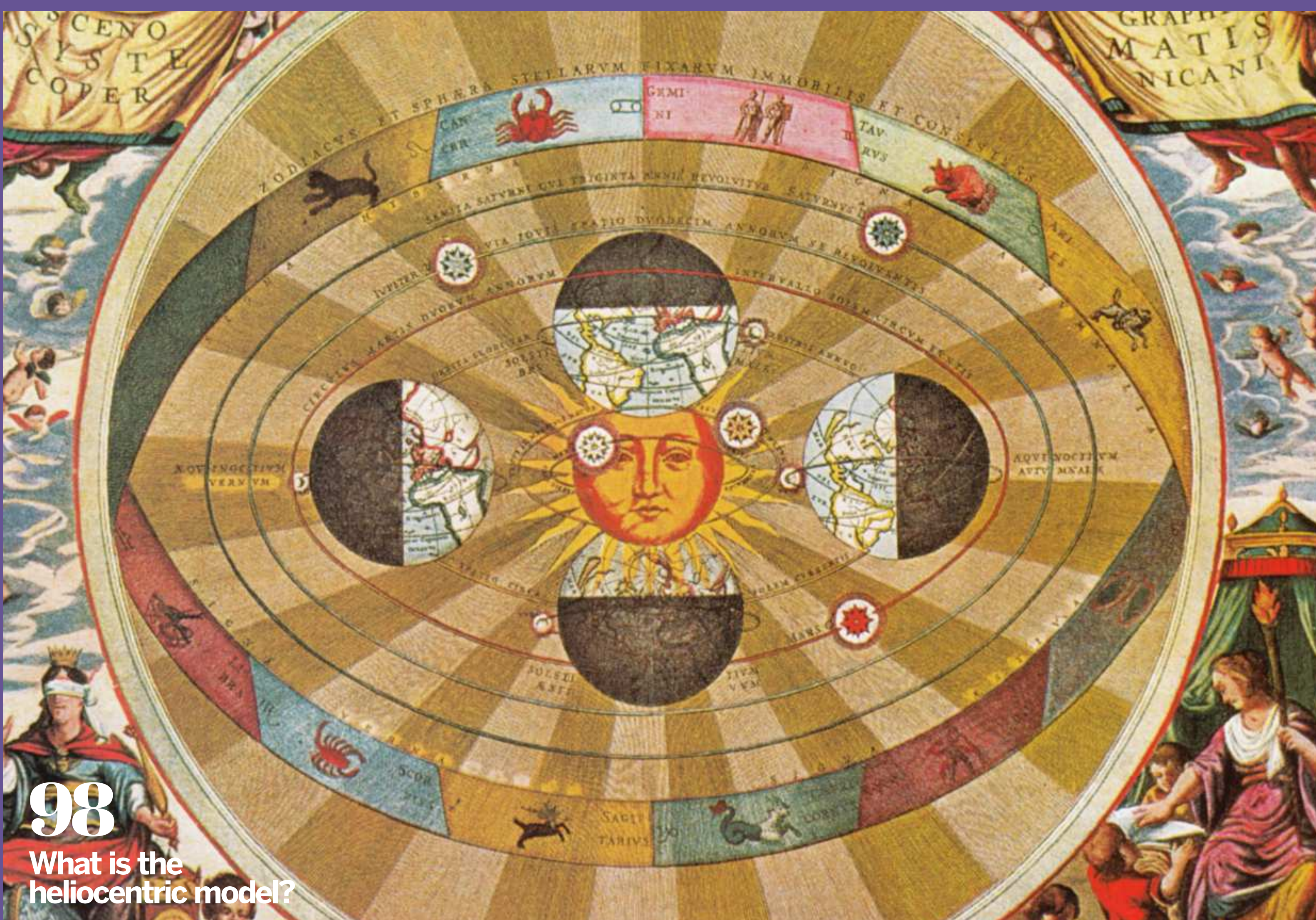
5 PREPARING FOR YOUNG
As new bee larvae grow in separate brood cells, honey cells are filled with honey in preparation for the new bees' arrival.

6 FEEDING THE YOUNG
When bee larvae have grown and hatch from their cells, honeybees feed them with the energy-rich honey they have collected. The honey is mixed with pollen to form 'bee bread' for extra nutrients.

The earliest record of humans eating honey is from 60,000 years ago

HISTORY

88
Who invented chess?



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What is the heliocentric model?

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Inside a medieval castle

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The Statue of Liberty

INSIDE A MEDIEVAL CASTLE

Discover the different types of castles that developed across the Middle Ages and how they were used

WORDS **JO ELPHICK**

When you think of the medieval period you likely imagine knights on horseback, jousting contests and, most important of all, a magnificent stone castle. But it wasn't just ruling monarchs who owned castles, and although these imposing buildings seem very British, they actually first appeared across Central Europe.

In order to understand why castles became so popular in medieval Europe, it's necessary to look at life in the Early Middle Ages. From 800 to 888 CE the Carolingian Empire controlled the majority of Western and Central Europe, just as the Roman Empire had before them. However, when the Carolingian way of life broke down, so too did the central government. Gradually, the nobles began fighting over individual pockets of land. Each lord wanted to regain power and control over his own area, and it wasn't long before violence broke out across the land.

As if this infighting wasn't bad enough, foreign warriors sensed the vulnerability of Europe after the fall of the Carolingian Empire and decided to attack. Vikings made their way to European shores and began pillaging the local villages while the Magyars of historic Hungary began looting raids all across central Europe.

Local lords took it upon themselves to set up their own individual governments, judicial systems and farming, but the continuous warring meant that they needed a way of protecting their personal estates. It was during this period of hostility that the first European castles were born. By using geographical features of the land such as cliffs, mountains and rivers, buildings could be partially defended – Bran Castle in Transylvania is a prime example of a perfect castle location. However, more was needed if the seats of power were to remain safe.

Ditches were dug, with the soil then used to create a steep hill or 'motte'. Fortified keeps were built on top with a wooden fence erected around

the perimeter. The lord and his family could live within the safety of the keep, protecting their personal wealth and ensuring that their government could survive attacks from neighbouring nobility who wanted to increase their own land and power.

William the Conqueror brought the castle to England in 1066. Having won the Battle of Hastings, he proceeded to build motte-and-bailey castles across the UK. Fortresses like Dunluce Castle, precariously perched on the rocky cliffs of Northern Ireland's coastline, took advantage of any natural land formations. It was protected on one side by the sea while the villagers settled outside the castle gate. If there was no geographical advantage, an artificial hill was created, such as the motte built in the centre of Windsor Castle, known as the Middle Ward.

The castle soon became a reward offered by the monarch to the nobles in return for their support. With the ever-present threat of a civil war, the king required reliable allies across the country who could quell unrest as it broke out among the people. These later 'gifted' castles were far more luxurious, offering the nobility a beautiful home as well as a secure place to hold administrative meetings.

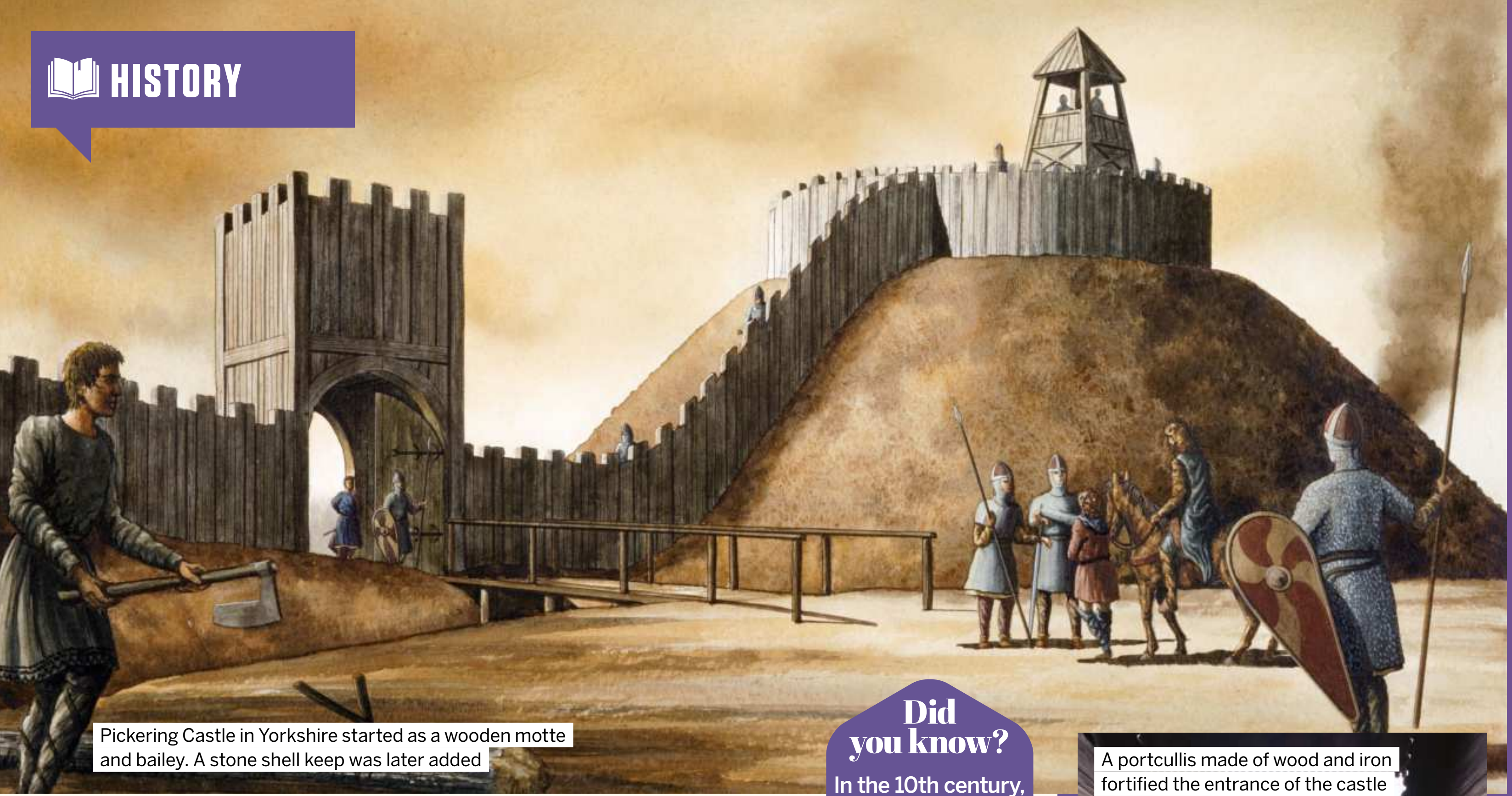
As time progressed and weaponry improved, castles needed to change their basic design and the materials used. Originally, windows were closed with wooden shutters, but these were later replaced with stone slits known as 'arrow loops' that made it very difficult for enemies to shoot their arrows through. Stone walls became thicker and higher, with crenulations that allowed guards to both fire their bows and arrows and to shield themselves from attack. However, with the arrival of the cannon even the fortified concentric castles crumbled, and the call for these draughty stone buildings dwindled away.


The Walls of Ávila in Spain depict the crenulations of a medieval castle

A MAN'S HOME IS HIS CASTLE

The broad definition of a castle is a large structure built to ward off attackers and keep the occupants and their belongings safe. It generally has extremely thick walls that can't be breached and battlements with accompanying towers where soldiers or guards can be placed to keep watch over the surrounding land. In order for it to be a castle and not just a fort, it also needed to be home to royalty or a wealthy lord. Ultimately, if the building acted as a fortress and a manor house, historians will consider it to be a castle.

© Getty



Pickering Castle in Yorkshire started as a wooden motte and bailey. A stone shell keep was later added

EVOLUTION OF THE EARLY STRONGHOLDS

Did you know?
In the 10th century, a castle cost about £100 ($123) to build

Early medieval strongholds, introduced during the Norman invasion of 1066, were known as motte-and-bailey castles. The 'motte' consisted of a large mound of earth with a tower placed on top. This was built from timber sourced from nearby forests. A fortified enclosure, or 'bailey', was surrounded by a wooden fence at the base. Many were built as the Normans settled in England, but it wasn't long before the warring Anglo-Saxons discovered a major flaw in the design. Wooden towers could easily be burnt down, and even if they were left untouched the wet weather soon began eating away at the vulnerable timbers.

Eventually, the wooden timbers were replaced with stone, thereby avoiding the obvious disadvantages of the wooden tower. The square Norman keep towers were a distinct improvement on their predecessors since they had far thicker walls, but there were still issues with the design. The corners had defensive blind spots, and although they were no longer threatened by an attack by fire, they were still easy to undermine.

By 1270, medieval castles had evolved into the concentric designs we think of today when imagining a castle, with multiple curtain walls and many fine gatehouses.

> "The 'motte' consisted of a large mound of earth with a tower placed on top"

A portcullis made of wood and iron fortified the entrance of the castle

Dunluce Castle is used as Pyke Castle of House Greyjoy in *Game of Thrones*

BUILDING UP

Early 900
Western and Central European nobles created fortified residences to protect their wealth and administrative functions from the Moors and Vikings.

1066
With a Norman victory at the Battle of Hastings, William the Conqueror introduced the concept of castles to England.

1067
Cheaply built motte-and-bailey castles were built close to William the Conqueror's landing site along England's south coastline.

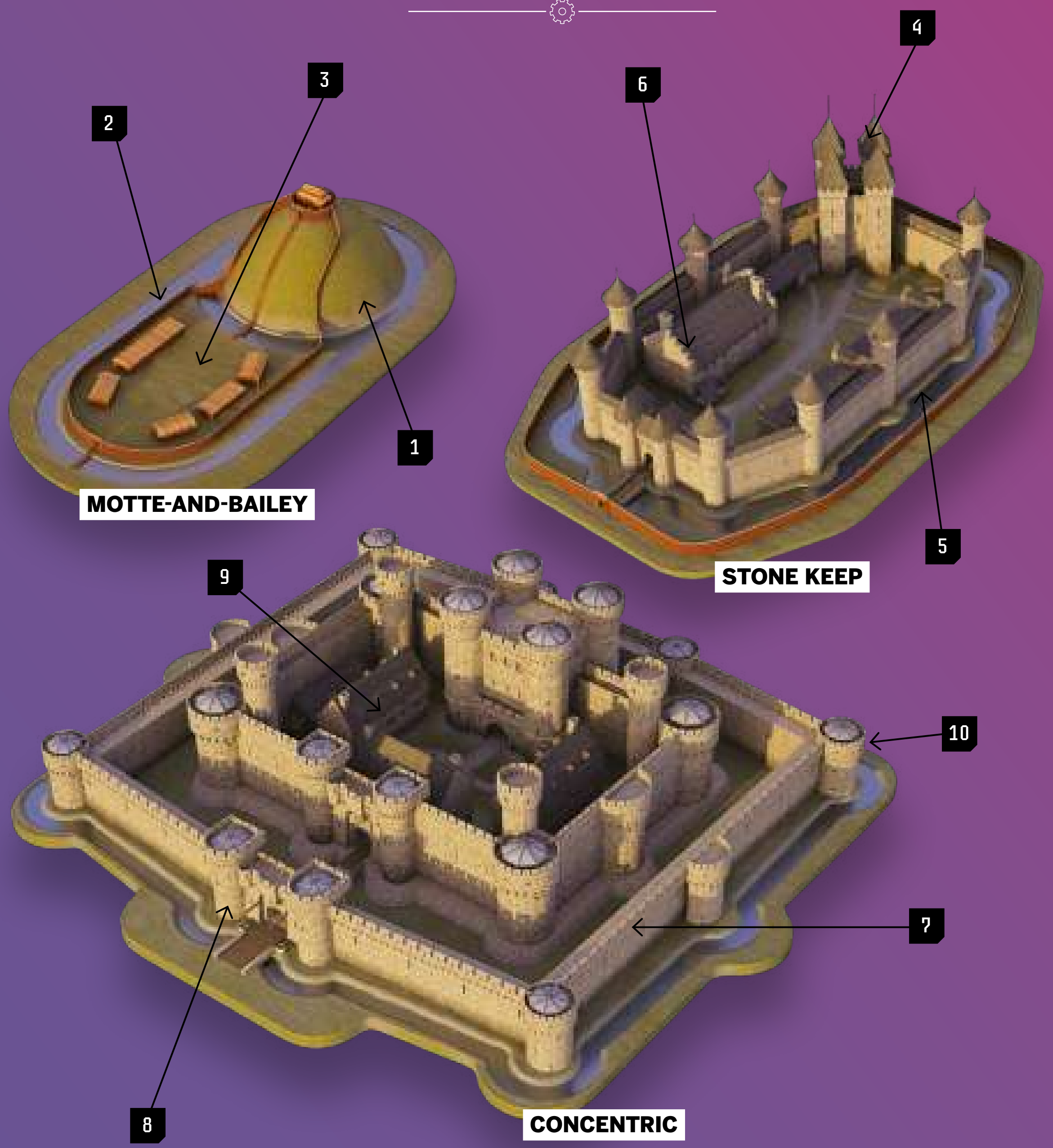
1072
William the Conqueror consolidated his power and motte-and-bailey castles spread across the British Isles.

1078
The original White Tower of the Tower of London was built by William the Conqueror using Kentish ragstone and mudstone.

DID YOU KNOW? The oldest standing castle in Europe is Château de Doué-la-Fontaine in France, which was built in 950 CE

CASTLE CHARACTERISTICS

Medieval castles came in three main flavours, each one a natural evolution in defence



1 MOTTE
The earthen mound could be up to 30 metres high. Steep sides called the 'scarp' made it difficult for intruders to climb up.

2 WOODEN PALISADE
This surrounded the bailey to keep the enemy out and was used in conjunction with a ditch that ran around its edge.

3 BAILEY
This courtyard contained domestic buildings such as the kitchens and stables and areas where the livestock could graze.

4 STONE KEEP
Stronger than a wooden tower, the stone keep was the improved living quarters of the lord and the last line of defence.

5 MOAT
A wide, deep ditch was dug around the castle and filled with nearby water to prevent intruders from reaching the walls.

6 GREAT HALL
Here the lord of the castle could hold banquets, reinforcing his status in the area.

7 CURTAIN WALLS
The double layer of protective walls had to be thick enough to withstand bombardment and too high for attackers to climb over.

8 THE GATEHOUSES
These entry points were protected by a metal grill, or 'portcullis'. Boiling oil was poured onto the enemy through 'murder holes' made in the ceiling.

9 DOMESTIC BUILDINGS
The kitchens, stables, a brewery and the water well were kept safe within the inner bailey.

10 TOWERS
Circular towers were strategically placed around the curtain walls to give archers a 360-degree view.

1087
William died, instigating battles between the new king and Norman nobility. Wooden palisades were replaced with stone walls called shell keeps.

1100
Motte-and-bailey castles were gradually replaced by more robust stone keeps.

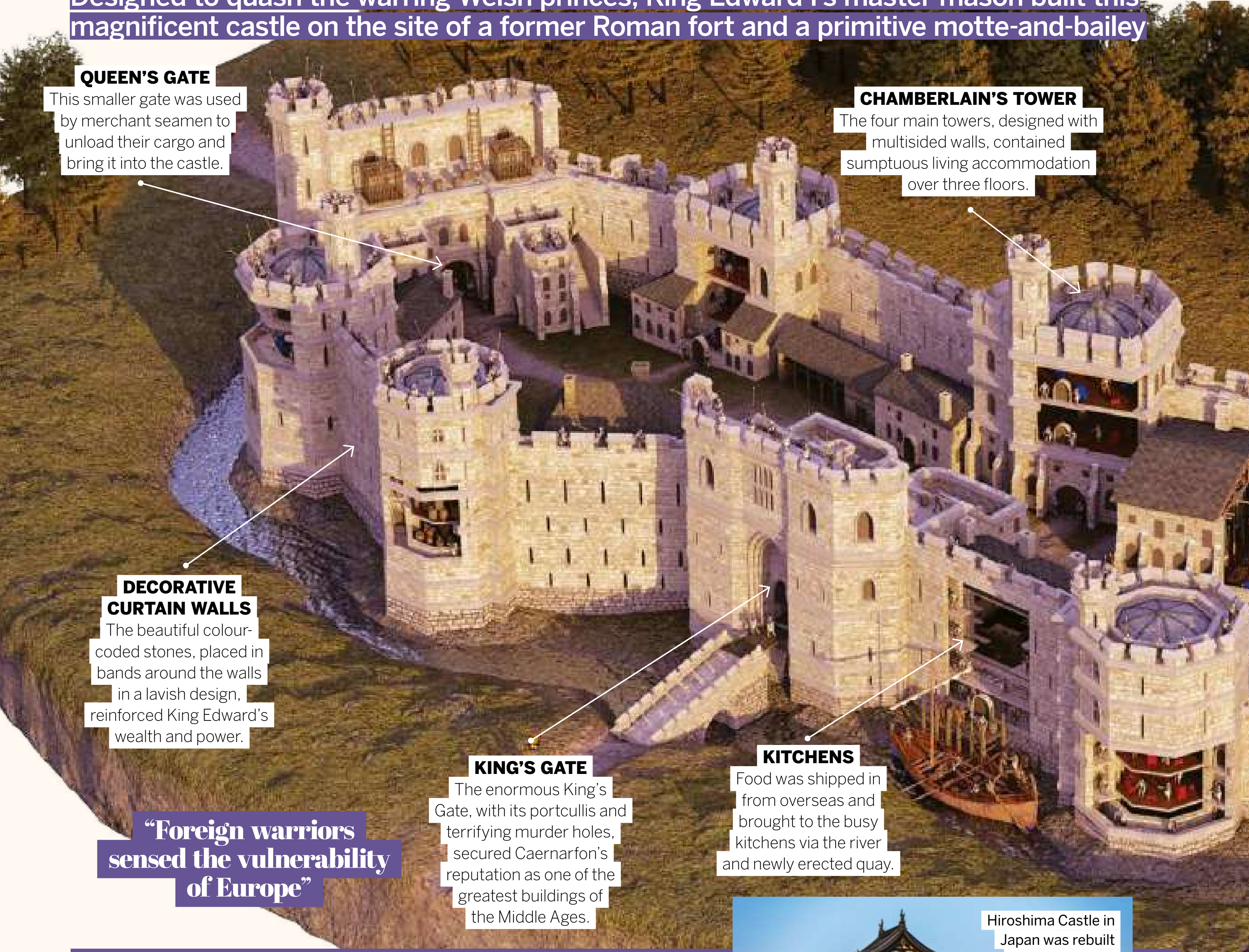
1199
Nobles had to acquire a 'licence to crenellate' from the king in order to fortify their homes into keeps.

Circa 1250
Curtain walls and towers were added to stone keeps, creating the first concentric castles.

Circa 1450
The arrival of improved military weapons such as the cannon meant that castles were no longer as popular, so they went into decline.

IMPOSING CAERNARFON CASTLE

Designed to quash the warring Welsh princes, King Edward I's master mason built this magnificent castle on the site of a former Roman fort and a primitive motte-and-bailey



> "Foreign warriors sensed the vulnerability of Europe"

CASTLES BEYOND EUROPE

Just as European castles were designed to act as both a fortress and a luxurious home, so too were the remarkable strongholds built further afield. Each country relied upon the natural contours of the area, such as a hill or a cliff, for security and utilised local resources to build their structure. Japanese castles were predominantly built of wood and stone and were created not only to safeguard, but also to show off the wealth of the feudal lords. The Citadel of Aleppo in Syria was made of limestone and was similarly designed to protect and impress. The medieval castle Fasil Ghebbi in Ethiopia included 12 gated towers to protect the royal family. It was the first two-storey building in the country.


Hiroshima Castle in Japan was rebuilt after the atomic bombing in 1945

DID YOU KNOW? The magical castle in Disney's *Sleeping Beauty* is based on a real castle in Germany called Neuschwanstein

Did you know?
Castle comes from a Latin word meaning 'fortress'

BIG AND WELL BUILT

HIMEJI CASTLE
Location: **Japan**
Year built: **1333**
Castle type: **Azuchi-Momoyama**
Size: **41,468 square metres**

NORWICH CASTLE
Location: **England**
Year built: **1067**
Castle type: **Stone keep**
Size: **93,077 square metres**

CAERPHILLY CASTLE
Location: **Wales**
Year built: **1268**
Castle type: **Concentric castle**
Size: **121,405 square metres**

MALBORK CASTLE
Location: **Poland**
Year built: **1274**
Castle type: **Concentric castle**
Size: **143,591 square metres**

HISTORY

WHO INVENTED CHESS?

How this challenging game has captivated minds for centuries

WORDS AILSA HARVEY

Chess is a sport, board game and a battle of brains. Although the core concept is simple – capture the opponent's king and declare 'checkmate' – the strategy and planning that take place as a game unfolds make for an intense, cognitive challenge. Nobody knows exactly who invented chess, but the earliest origins of the game can be traced back to India, China and Persia over the course of 15 centuries. Chess was eventually introduced to Europe some time before 1,000 CE, partly due to the travelling of merchants. As people voyaged over long distances for trade, many would take chess sets with them to occupy themselves. Some impressive carved chess pieces produced in different regions of the world were transported overseas, and thus interest in and knowledge of the game grew.

In Europe during the Middle Ages, chess became so popular that individuals regarded as upper class were expected to know the rules of chess, with techniques being passed down to new generations. Meanwhile, Arabic countries still played a similar game called Shatranj, parts of which chess evolved from. The organised international chess competitions that are popular today only started in the 19th century. Of the many varieties of the game, a single set of rules was decided upon. These continue to change slightly over time, with the latest rule change taking place in 2014. The International Chess Federation works to make this lasting, cultural game a fair and modern sport.

MIXED ORIGINS

Chess wasn't born in a day. Being a complex and tactical affair, the rules evolved over time. The earliest predecessor of chess was a game called Chaturanga, which was invented in India over 1,500 years ago. Like chess, the object of Chaturanga is to 'checkmate' your opponent's king. Instead of the two-sided game that is displayed in chess, Chaturanga included four different 'armies', each beginning play in one of the four corners of the board. Each player represented one of the divisions of the Indian military: infantry, cavalry, elephantry and chariotry.

Taking away some of the choice of tactics, the earliest versions used a dice to determine which piece could be moved. While similarly designed with horses, rooks and pawns, some of the pieces used in Chaturanga were different to today's chess pieces. Instead of a bishop, an elephant was used, while a minister took the place of the queen. The king took a similar position on the board, but unlike in chess, where the king's position depends on its colour, in Chaturanga the king remains on the right of its advisor for all players.

AN ANCIENT GAME

EARLIEST SURVIVORS

The earliest surviving chess pieces consist of seven ivory ornaments that were dated to 760 CE. These pieces were abstract in design due to Islamic law preventing figurative art. These were also made using bone or wood in some instances.

CHRISTIAN INFLUENCE

Chess pieces carved from Walrus tusk and whale teeth in the 12th century were found on the Scottish Isle of Lewis in 1831. The chunky chess set is thought to have originated in Iceland and includes the oldest known Christian bishop in chess.

DARK AGES

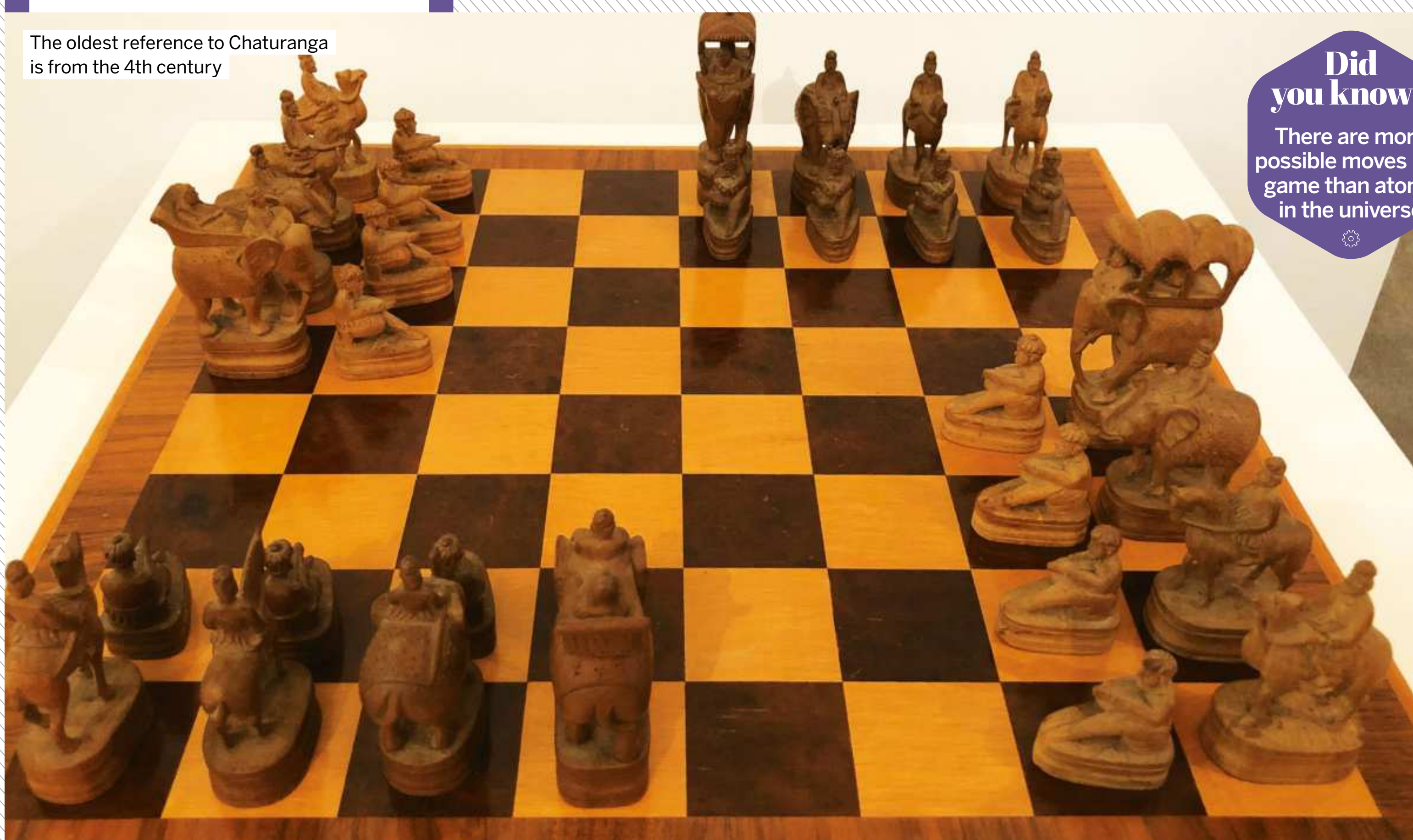
Small ivory pieces less than five centimetres in height were uncovered in the ancient Mediterranean city of Butrint, Albania, in July 2002. Some historians believe that this set could date to 465 CE. If this is correct, then these pieces are the oldest known physical evidence of the game.

OLDEST EUROPEAN

In 1958, the oldest known European chess pieces were discovered. The four Mozarab pieces were made using deer antlers and were preserved in the Mozarabic monastery of Santiago de Penalba, Spain.

Some of the oldest chess pieces were carved from ivory and painted

93 medieval chess pieces were discovered on a Scottish island



The oldest reference to Chaturanga is from the 4th century

Did you know?

There are more possible moves in a game than atoms in the universe

AN EVOLVING GAME

These events took the next move in the evolution towards today's game

TIMELINE FACTS

Chinese chess is also known as Xiangqi

600 CE
An Arabic game named Shatranj emerged from the Indian game Chaturanga, more closely resembling chess.

5,949
The longest chess match possible has thousands of moves

800 CE
Chess began to spread to the rest of the world, with the first iteration of Chinese chess introduced by Buddhists from India.

26 YEARS, 337 DAYS
Emanuel Lasker remained World Chess Champion longer than any other player

1561
The term 'gambit' was first used to describe tactical sacrifices of pieces.

1575
The first informal chess tournament took place between Spanish and Italian chess players.

Giovanna Leonardo di Bona and Ruy López took part in the first chess tournament

1744
18-year-old François-André Danican Philidor played two simultaneous games while blindfolded.

1849
The official chess pieces – today's Staunton style – were designed, named after English chess playe Howard Staunton.

1861
The first chess timers were used in chess matches, with three hours of sand inside.

1886
An Austrian-American player named William Steinitz became the first world chess champion.

ORIGINALLY, THE QUEEN COULD ONLY MOVE DIAGONALLY AND JUST ON SQUARE PER MOVE

169,518,829, 100,544,000,000, 000,000,000
The number of ways to play the first ten moves of a chess match is in the octillions.

1997
A computer beat a chess champion, Garry Kasparov, for the first time.

CHECKMATE COMES FROM THE PERSIAN PHRASE 'SHAH MAT', MEANING 'THE KING IS DEAD'

2013
Norwegian chess player Magnus Carlsen became World Champion in 2013 and remains the world's top player.

5 CHESS LUMINARIES

1 SISSA IBN DAHIR
According to Indian legend, Sissa invented Chaturanga as a gift for King Shirham of India and taught many of the king's ministers the game. Sissa described chess as a game for intelligent people with good memory.

2 HAN XIN
Chinese military leader Han Xin is credited with inventing the Chinese version of chess in 200 BCE to represent a battle he was involved in. The rules of this variation quickly spread around the world.

3 KING XERXES OF PERSIA
Portuguese chess player and author Pedro Damiano named King Xerxes the inventor of chess in one of the oldest comprehensive chess books available. The terms 'check' and 'checkmate' also originated in Persia.

4 RUY LÓPEZ DE SEGURA
In the late 1500s, this Spanish priest demonstrated a new opening move which proved successful in international tournaments. These moves have shaped modern strategies, with many people choosing the 'Ruy López Opening' as the best way for White to gain quick control.

5 FRANÇOIS-ANDRÉ DANICAN PHILIDOR
This French musician was regarded as one of the best chess players of the 18th century. A checkmate method and unique chess opening were his strategies, and are both named after him today.

DID YOU KNOW? Chess rules changed in 1280 to allow the pawn to move two squares on its first move

THE SECOND BOOK EVER PRINTED IN THE ENGLISH LANGUAGE WAS WRITTEN ABOUT CHESS

900 CE
In the late 900s, light and dark squares were added to chess boards.

20 HOURS
The longest official game was 269 moves

1450
To speed up the game, a rule change called 'mad queen' allowed the queen to move as many spaces as the player wished.


The queen is now considered the most powerful chess piece.

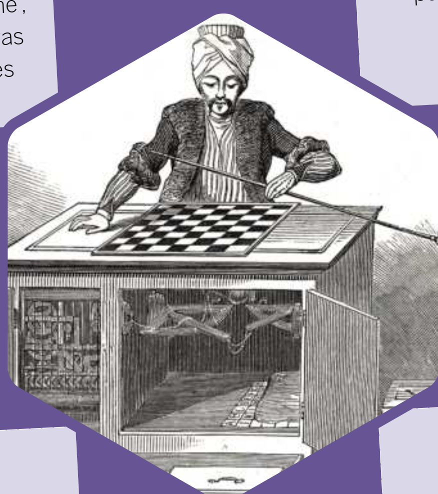
100
The record number of moves with no pieces captured

1690
Different chess opening strategies were analysed and systematically classified.

1769
Hungarian inventor Wolfgang von Kempelen demonstrated a magic 'chess-playing machine', but a hidden player was controlling the pieces with magnets.

600,000,000
Around 600 million people know how to play chess

1830
The earliest evidence of a female chess player was published in the US



IN 1936, ALBERT EINSTEIN SAID "I DO NOT PLAY ANY GAMES. THERE IS NO TIME FOR IT." BUT HE TOOK UP CHESS LATER IN LIFE

FOLDING CHESS BOARDS WERE INVENTED IN 1125 BECAUSE A PRIEST WAS FORBIDDEN FROM PLAYING CHESS

1924
The World Chess Federation, also called the Fédération Internationale des Échecs (FIDE), was established.

1958
American chess player Bobby Fischer became the youngest Grandmaster at the age of 14. This record remained for over three decades.

CHEATING AND CONTROVERSY

Chess comes with complex rules and extensive possibilities. The sport represents tactical skill and intelligence, and so there are many precise elements that can be disagreed on. Throughout history, competitions have caused moments of speculation and even represented the power of whole countries. In 2006, Vladimir Kramnik and Veselin Topalov went head to head, with Kramnik winning. However, his frequent toilet trips led to Topalov and his team accusing him of cheating in these breaks. In every chess match that followed between them, this hostility remained, and the two players refused to shake hands.

Cheating has been suspected in many other matches. In 1978, Anatoly Karpov had a hypnotist on his team, causing opponent Viktor Korchnoi to start wearing reflective glasses during play to avoid entering a trance. Korchnoi also accused Karpov of receiving coded messages written in his yoghurt during the game. In 1972, while the Cold War continued, a chess match between US player Bobby Fischer and Russia's Boris Spassky served as a metaphor for the conflict. Fischer won the intellectual battle between countries, ending 24 years of Russia's dominance on the chess board. During a match of particularly high tension, the Russian side thought that Fischer was poisoning Spassky and releasing low-frequency sound waves in his chair to distract him. Fischer's chair was X-rayed and cleared.

Did you know?
Many top World War II codebreakers were chess players


Bobby Fischer (right) playing against Boris Spassky (left)

THE STATUE OF LIBERTY

How one of the most iconic statues in the world was constructed

WORDS SCOTT DUTFIELD

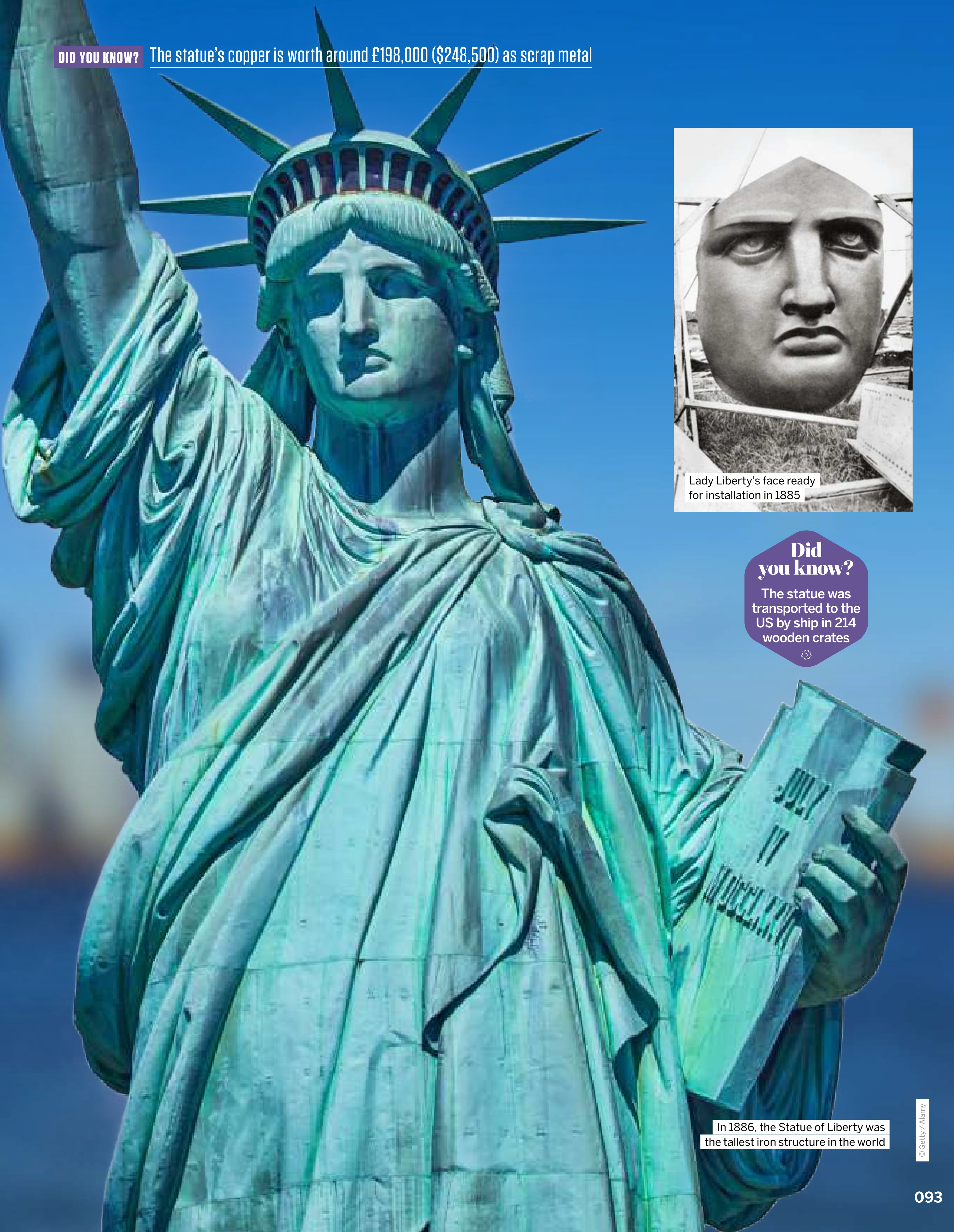
The Statue of Liberty has long been a symbol of freedom and hope. Its official title is *Liberty Enlightening the World*, named by its sculptor Frédéric Auguste Bartholdi. Also called Lady Liberty, the historic landmark was created to commemorate the centenary of the Declaration of Independence, along with America's close relationship with France, who gifted the statue in the late 1800s. The initial concept came from the French poet, author and activist Édouard René de Laboulaye. It's often reported that Laboulaye came up with the idea at a dinner party in 1865 following the assassination of Abraham Lincoln, but studies have found this to be false. Evidence suggests that Laboulaye conceptualised the statue between 1870 and 1871. The statue's creation also recognised the American ideals laid out in the Declaration of Independence following the end of the American Civil War and the abolishment of slavery. Lady Liberty has also been described as the 'Mother of Exiles' by the millions of immigrants that have turned to America for refuge.

Funding for the statue fell to both nations; the copper statue was financed by the French public through lotteries, entertainment events and public fees, whereas the stone pedestal on which it stands was funded by the US through theatrical events, auctions and a lucrative opportunity for donors to have their names printed in *The New York World* newspaper by the renowned Joseph Pulitzer.

In Paris her copper body was constructed in segments; in the US, Charles Pomeroy Stone was appointed engineer-in-chief for the construction of the pedestal. At a workshop in Paris, Bartholdi created a plaster cast of the Statue of Liberty around one-fourth the size of the final sculpture. Using his model, carpenters built wooden moulds around sections that would then be used to shape a single sheet of copper into a section of the final statue in a technique known as repoussé.

A sheet of thin copper was laid over the mould and hammered into the contours, recreating the shape of the study model in copper panels. It took 350 copper panels to complete. Beneath her copper skin is a network of iron frames that create the

DID YOU KNOW? The statue's copper is worth around £198,000 ($248,500) as scrap metal

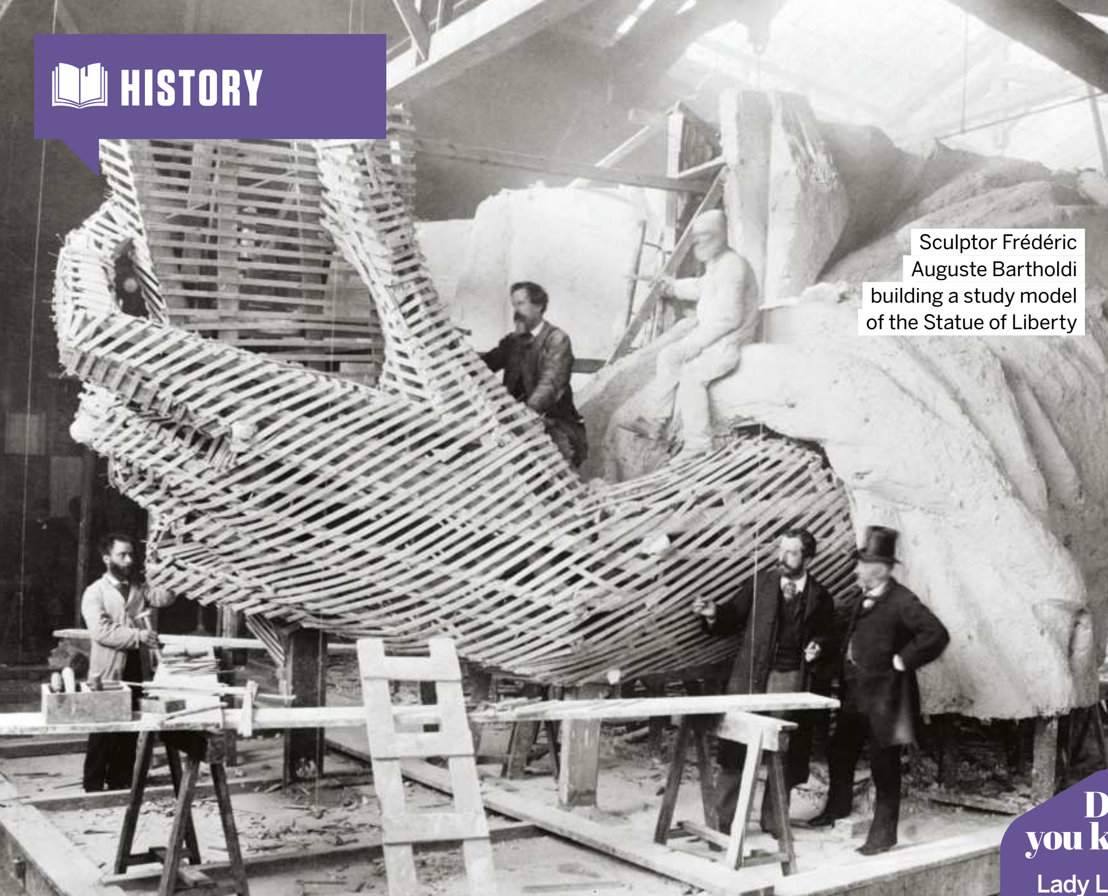


Lady Liberty's face ready for installation in 1885

Did you know?

The statue was transported to the US by ship in 214 wooden crates

In 1886, the Statue of Liberty was the tallest iron structure in the world



Sculptor Frédéric Auguste Bartholdi building a study model of the Statue of Liberty

skeleton. The internal metalwork was designed by French engineer Gustave Eiffel, who later constructed the eponymous tower. In the centre of the statue is an iron pylon, or 'spine', that runs from the base to the top and carries the entire weight. Each copper panel is connected to the iron skeleton via individual iron straps – this means that none of the copper panels bear the weight of the panel above.

Construction was completed in anatomical stages. The torch-wielding arm was finished in 1876, the head and shoulders by 1878 and the rest of the body by 1884. At this point, work on the stone pedestal in the US was underway. On a trip to the States in 1871, Bartholdi selected Bedloe's Island – now known as Liberty Island – as the site for the statue, visible from New York Harbour to be seen as the 'gateway to America'. He decided the structure would sit in the centre of Fort Wood, an 11-point-star-shaped fort built in the 19th century. The already-bomb-proof fort was strengthened with concrete to bear the weight of the granite and concrete pedestal.

Once the pedestal was built, the copper sculpture could be reconstructed and mounted on top. The statue reached New York Harbour in 1885, having travelled more than 5,000 miles across the Atlantic Ocean aboard a French Navy ship. It was transported disassembled, ready for reconstruction once the pedestal was completed in 1886. Only a few months after the pedestal's completion, the statue was erected, unveiled to the world the same year. People came from far and wide to visit the copper beacon of freedom, but by 1920 visitors of the once-copper giant were greeted by the blue-green coating.

The colour transformation is the result of a chemical process called patination, whereby a layer of patina forms on top of the copper when it is exposed to the air. Over three decades the copper has gone through a series of oxidation reactions, where an element loses electrons in chemical reactions. In the first few months of standing in the open air, the copper panels reacted to oxygen in the atmosphere, forming a reddish mineral called cuprite. After a year or two, the statue became dark brown as cuprite further oxidised to form a black mineral called tenorite. After around three to four years the Statue of Liberty would have been a much darker brown colour thanks to the build up of tenorite.

As human activity increased within New York City, so did the emission of a pollutant called sulphur dioxide. Once in the atmosphere, sulphur dioxide mixed with water and rained down on the statue, causing a chemical reaction with the

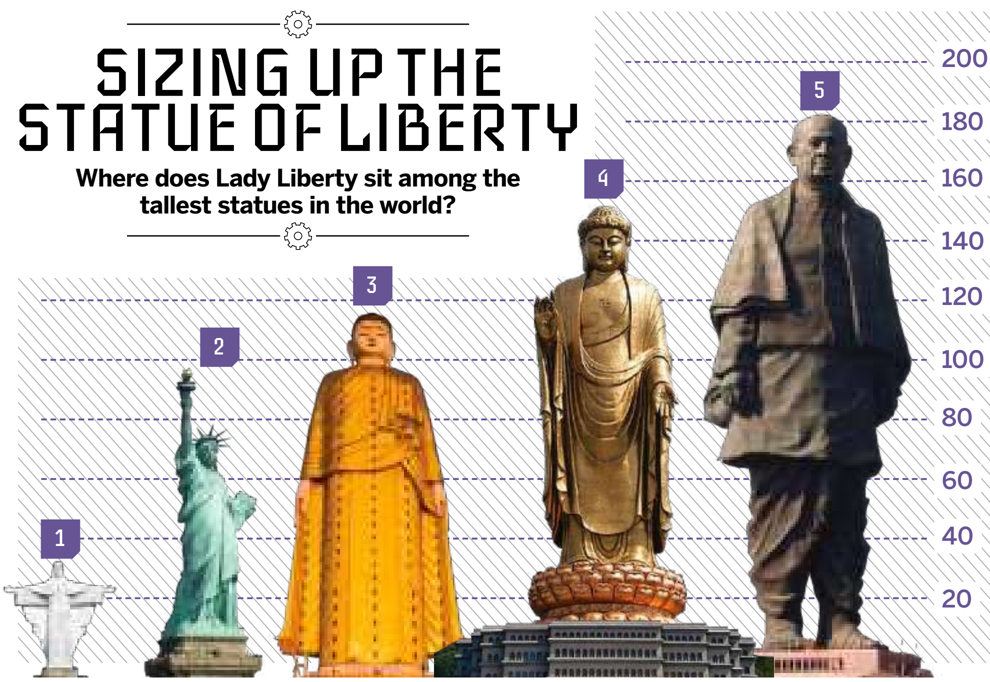
Did you know?

Lady Liberty's shoe size is 879

The copper statue in Paris before being dismantled and shipped to America

SIZING UP THE STATUE OF LIBERTY

Where does Lady Liberty sit among the tallest statues in the world?



1 CHRIST THE REDEEMER
Country: **Brazil** Height: **30 metres**

2 THE STATUE OF LIBERTY
Country: **US** Height: **93 metres**

3 THE LAYKYUN SEKKYA BUDDHA
Country: **Myanmar** Height: **116 metres**

4 THE SPRING TEMPLE BUDDHA
Country: **China** Height: **153 metres**

5 THE STATUE OF UNITY
Country: **India** Height: **182 metres**

tenorite and creating a green mineral called brochantite. As more brochantite became exposed to sulphur dioxide, it became a greener mineral called antlerite. In addition, sprays of chloride from the nearby ocean created patches of green atacamite in places where the rain couldn't wash it off.

The original copper isn't completely lost. The patina coating works as a protective layer – now almost as thick as the copper walls themselves – and prevents the metal beneath from eroding. However, the same can't be said for her iron skeleton. In 1984 restoration missions were carried out to repair holes and replace rusting iron bars with stainless-steel alternatives. Two years later the restorations were complete, along with a new illuminating flame for all who ventured near the harbour to see.

A NEW FLAME

The torch is one of the statue's most recognisable elements, but the current flames are not those installed in 1886. Bartholdi's design called for a copper flame coated in a layer of gold leaf, illuminated by a series of lights around the balcony to bring the flames to life. Unfortunately, Bartholdi's ideas for the torch were abandoned due to fears its bright light might blind passing pilots. After exploring several options for how the torch should be built and used – it was even proposed that the statue could be utilised as a lighthouse at one time – it was created out of multiple panes of glass with a bright bulb within. In 1984 enthusiasm for Bartholdi's original designs was re-ignited following restorations, and the torch was replaced with a 24-karat-coated flame illuminated by a ring of floodlights. The statue's original torch now sits inside the Statue of Liberty Museum.

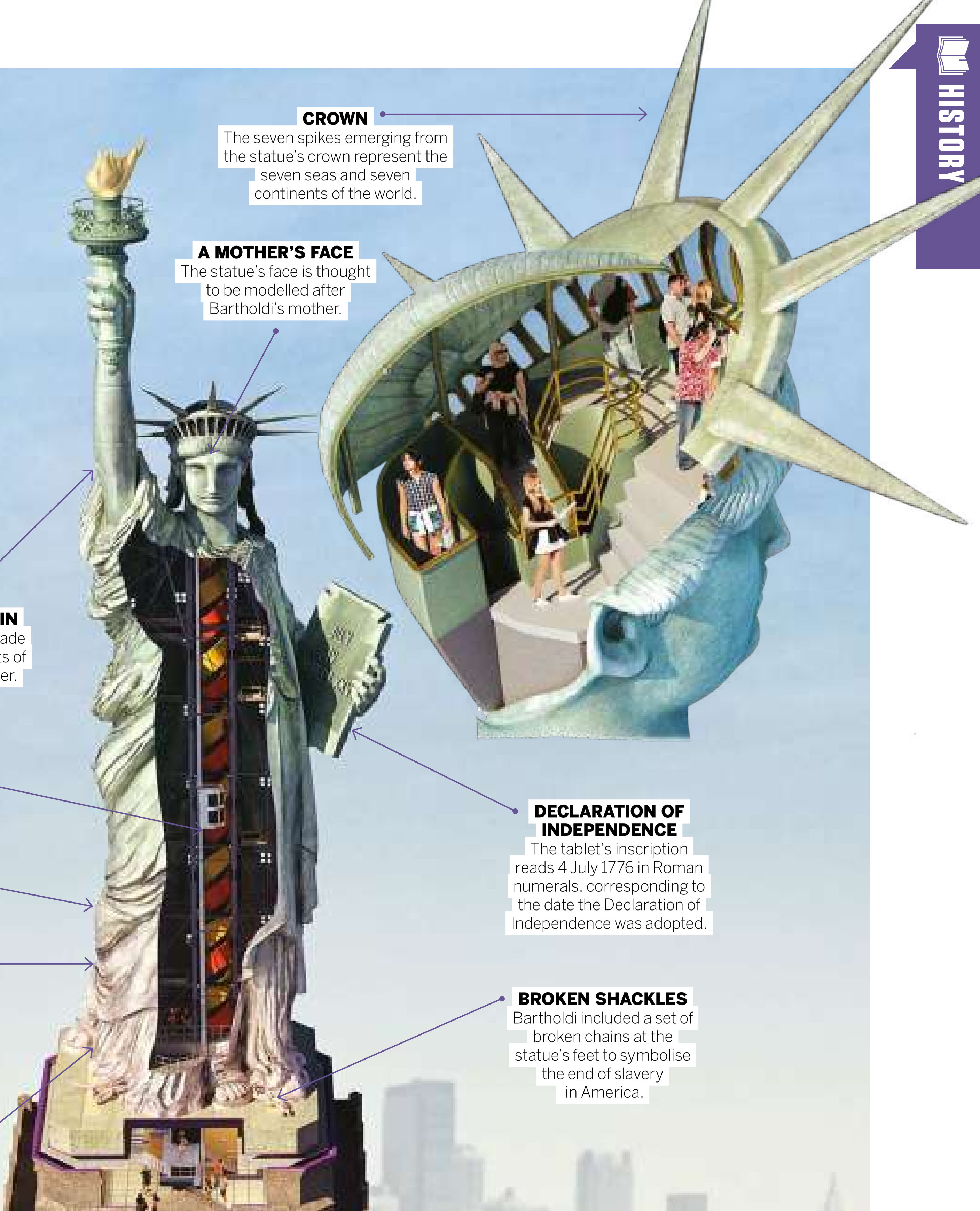
The original torch on display in the Statue of Liberty Museum

GOING GREEN

How the colour of Lady Liberty has changed with age

INSIDE THE STATUE OF LIBERTY

Take a tour of *Liberty Enlightening the World*



CROWN
The seven spikes emerging from the statue's crown represent the seven seas and seven continents of the world.

A MOTHER'S FACE
The statue's face is thought to be modelled after Bartholdi's mother.

COPPER SKIN
The statue is made up of 300 sheets of coin-thin copper.

IRON SPINE
Four iron columns support the statue's framework.

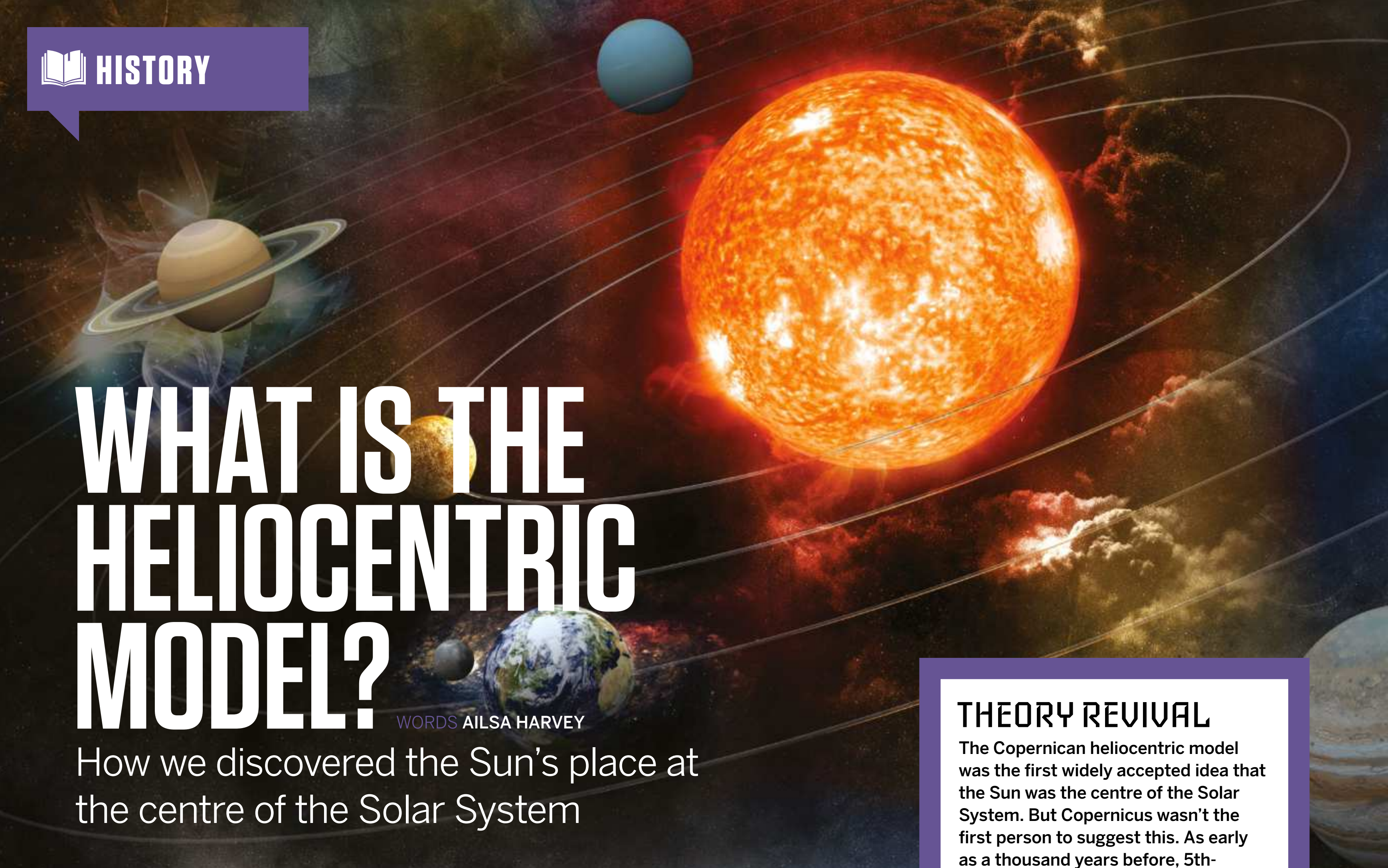
COLOUR CHANGE
Over 30 years the copper statue developed a blue-green patina.

THE WEIGHT OF LIBERTY
The copper in the statue weighs 27.2 tonnes. The skeleton adds 113 tonnes, all sitting on a 24,500-tonne stone pedestal.

DECLARATION OF INDEPENDENCE
The tablet's inscription reads 4 July 1776 in Roman numerals, corresponding to the date the Declaration of Independence was adopted.

BROKEN SHACKLES
Bartholdi included a set of broken chains at the statue's feet to symbolise the end of slavery in America.

© Illustration by nicholas Forder



WHAT IS THE HELIOCENTRIC MODEL?

WORDS AILSA HARVEY

How we discovered the Sun's place at the centre of the Solar System

Where are we in the universe? It's a simple question when analysing our immediate cosmic whereabouts, but how did astronomers learn of our position in the Solar System? Today we know that Earth and the other planets surrounding us are all in orbit around the Sun. However, it was once believed that Earth was at the centre of what was thought to be the entire universe, and that everything revolved around us. This is now known as the geocentric model, while the heliocentric model puts the Sun rightly at the centre. Nicolaus Copernicus proposed the heliocentric model in his work published in 1543. While his theory of the Sun being central was correct, the model in its entirety held many inaccuracies. Because the heliocentric model was initially pieced together before telescopes existed, all observations had to be made with the naked eye and simple instruments. The positions of planets were predicted largely by observing their position and size against the stars.

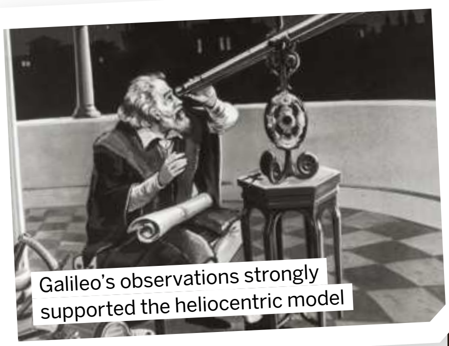
Did you know?

The Catholic Church was strongly against the theory

WHY WAS THIS MODEL SO IMPORTANT?

By answering the question of what was at the centre of the Solar System, astronomers were able to find the answers to other questions too. Mercury and Venus' orbits were placed between the Sun and Earth, revealing to astronomers why they appeared so different in size and shape over time. When the planets were on the far side of the Sun relative to the position of Earth, the bodies appeared much smaller in the sky. When on one side of the Sun, the light hitting the planets gave them a crescent shape to observers.

Almost a century after Copernicus' theory was released, scientists such as Johannes Kepler, Galileo Galilei and Isaac Newton were able to use the heliocentric model to make new findings. Kepler and Newton worked out precise measurements of the planets' movements around the Sun, while Galileo used his telescope to prove heliocentrism.

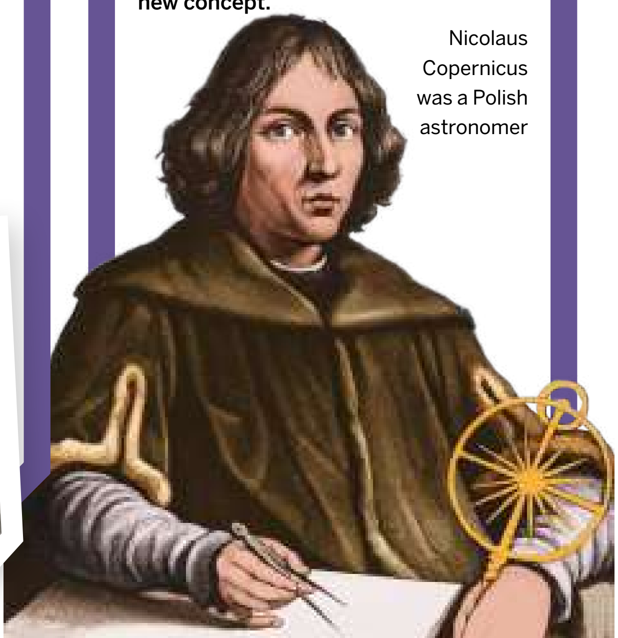


Galileo's observations strongly supported the heliocentric model

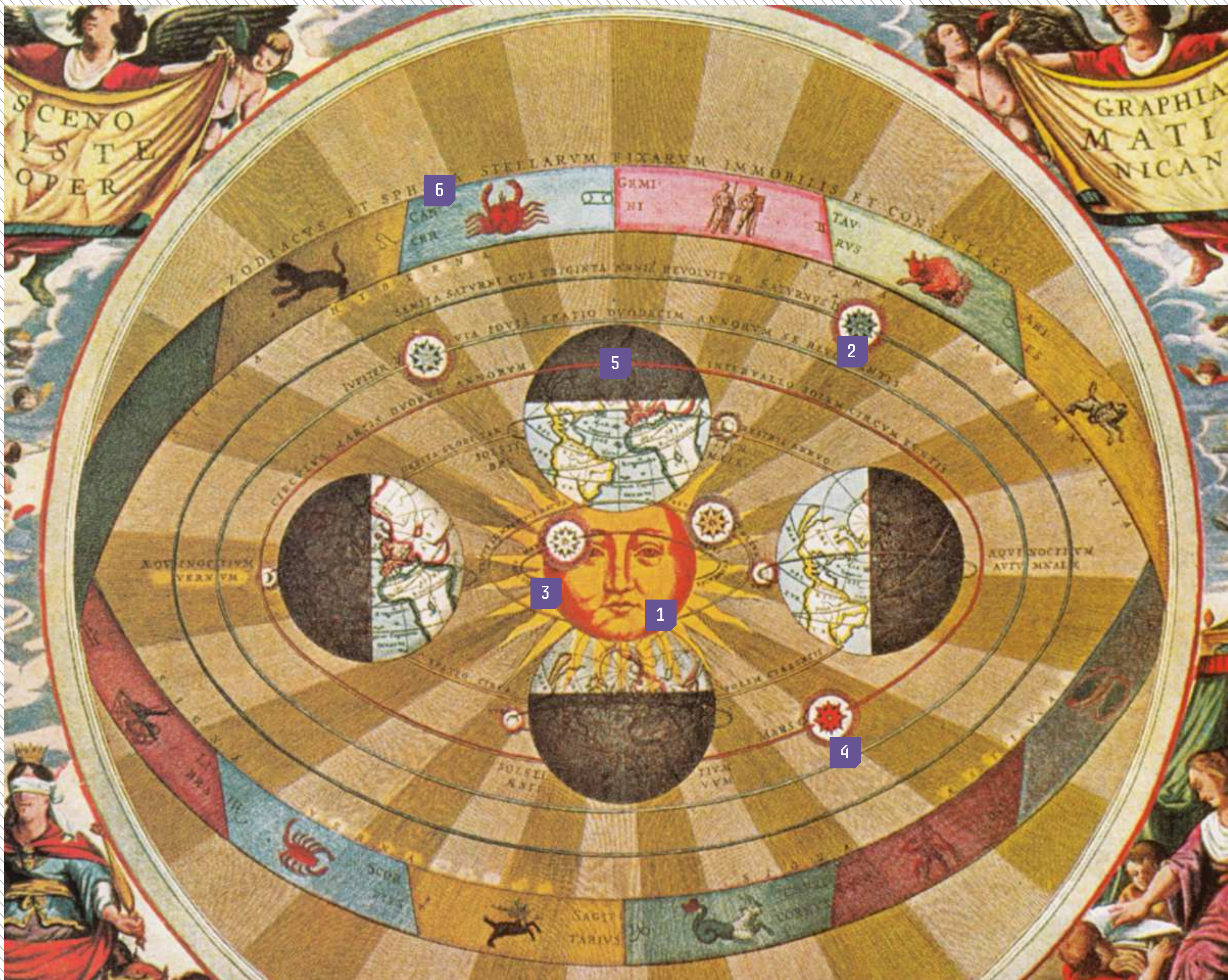
THEORY REVIVAL

The Copernican heliocentric model was the first widely accepted idea that the Sun was the centre of the Solar System. But Copernicus wasn't the first person to suggest this. As early as a thousand years before, 5th-century Greek philosophers Philolaus and Hicetas suggested that the Earth could be circling a fiery object. Greek astronomer Aristarchus of Samos suggested that this object was the Sun two centuries later.

Because no one was able to explain why the stars looked the same despite Earth changing position, the geocentric model became more widely recognised. Egyptian astronomer and mathematician Claudius Ptolemy overcame this problem with a new theory – that Earth was fixed at the centre of the Solar System. This theory remained popular for around 1,400 years, which made the revival of the heliocentric model seem like a new concept.



Nicolaus Copernicus was a Polish astronomer



COPERNICAN HELIOCENTRISM

What did Copernicus' heliocentric model look like in 1543?

1 STATIC SUN
Copernicus thought that the Sun was stationary in its central position.

2 ORBITING SPEED
In the original heliocentric model, the planets orbited the Sun at the same speed.

3 CENTRAL SUN
Copernicus placed the Sun close to the centre of the universe, but not at the exact centre.

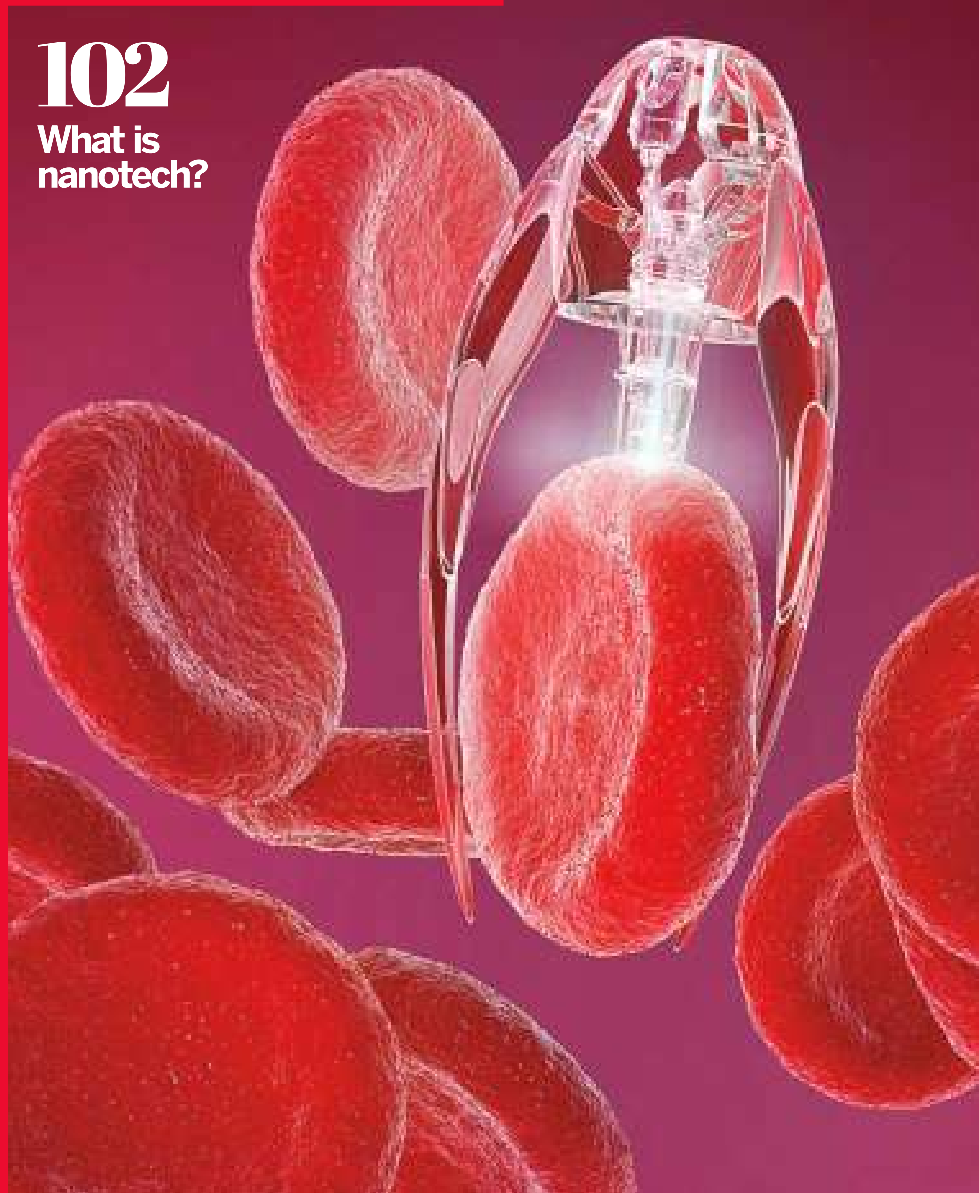
4 PLANET ORDER
According to this model, the planet order is Mercury, Venus, Earth, Mars, Jupiter, Saturn and the stars.

5 ROCKY EARTH
In previous models, people believed that the other planets were made of entirely different materials to Earth. The heliocentric model helped scientists realise Earth was more like the other planets.

6 FIXED STARS
In this model, the stars don't move. They appear to move in the opposite direction due to Earth's rotation.

Nicolaus Copernicus' published heliocentric model

TECHNOLOGY



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What is nanotech?

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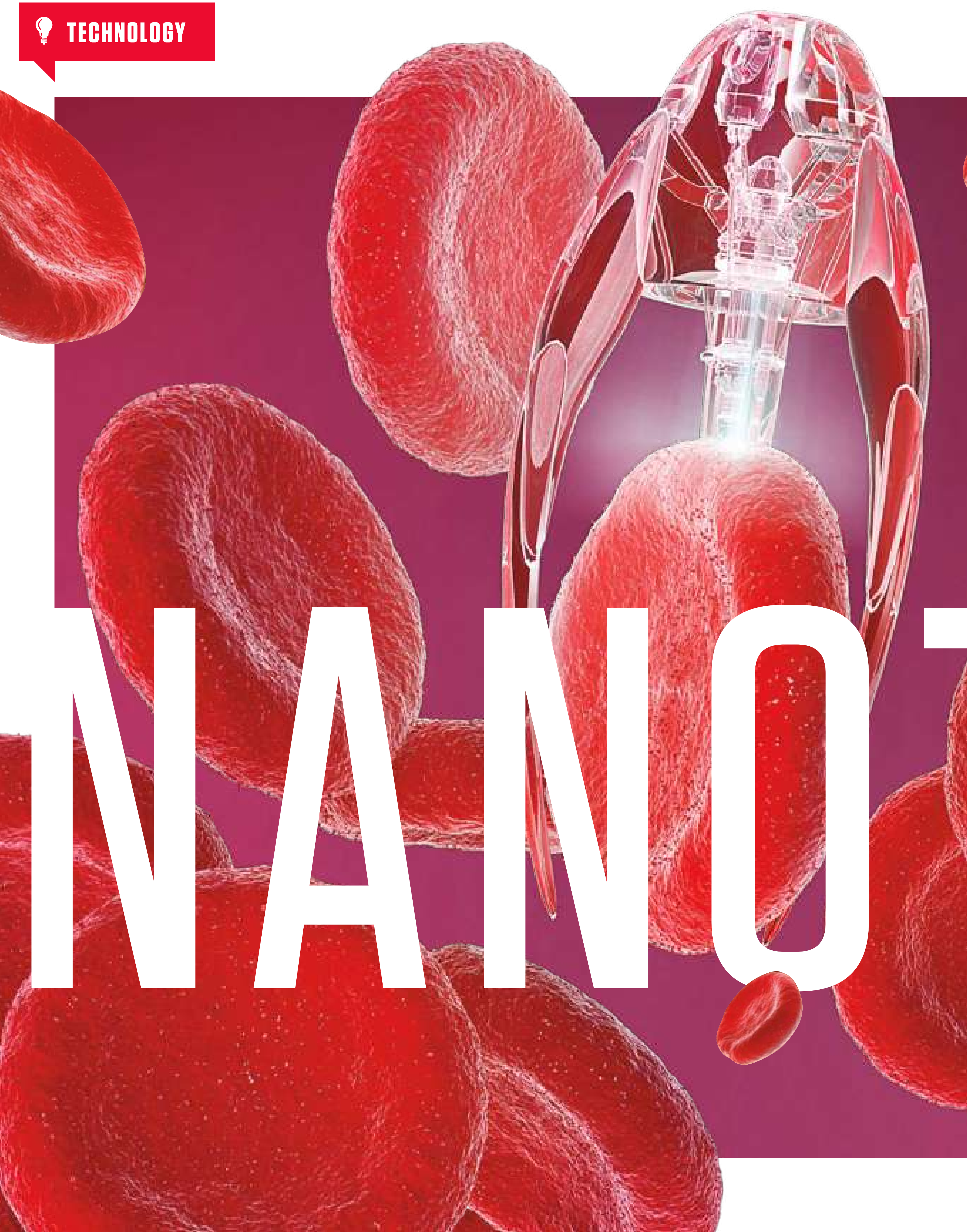

NANO

WHAT IS TECH?

Enter the invisible world of tiny machines and materials, where everything measures 0.0001 millimetres or less

WORDS LAURA MEARS

© Getty

Factories make graphene by forcing ions between layers of graphite to peel them apart

The smallest object visible to the naked eye is a human egg cell. It measures just 0.1 millimetres in length. Beyond that limit, the world is completely invisible. Nanotechnology is the field of science and engineering at a scale of one to a hundred nanometres. That's a thousand to a hundred thousand times smaller than the smallest thing we can see.

Particles at this tiny scale behave completely differently to the full-size structures we are used to. Gold changes colour from yellow to purple and becomes liquid at room temperature. Carbon transforms into an extraordinary electrical conductor. And copper gains the ability to kill bacteria. Discovering this invisible world and harnessing its power is the domain of nanotechnology.

Did you know?

Nanofibres can filter pollutants from indoor air

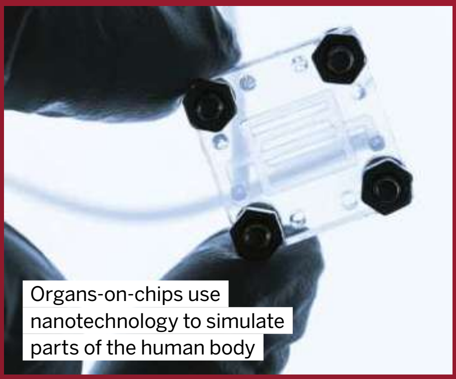
The first person to measure and name a nanoparticle was Richard Zsigmondy. Awarded the Nobel Prize in Chemistry in 1925 for his efforts, he was fascinated by ceramics and glass. Their stunning colours were the result of nanoscale particles known as colloidal gold, which reflect light in unusual ways. But it wasn't until the 1950s that people started to experiment with using nanoparticles like these in different ways. During the Cold War, another Nobel Prize winner, Richard Feynman, was investigating the possibility of science on an atomic scale. He published a paper entitled *There's Plenty of Room at the Bottom*, inviting scientists to enter a new field of physics. Feynman wanted to miniaturise computers and create machines that could assemble molecules atom by atom. And he dreamed of a day when you could 'swallow your surgeon', delivering a life-saving robot into your body.

His ideas might sound like science fiction, but nature had already proven they were possible. Inside every single cell there are millions of molecules, each measuring just fractions of a millimetre across. These particles can perform both mechanical and chemical work; they self-assemble and self-heal, and they also store and exchange information. They are nature's nanomachines – all we have to do is recreate them.

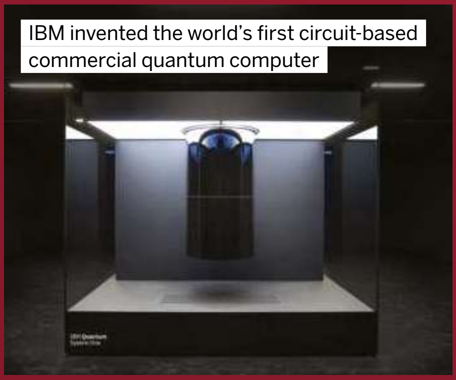
In the 1980s, two powerful new microscopes revealed the nanoworld in all its minute detail. The scanning tunnelling microscope used a very fine wire and an electric current to map even the thinnest of materials. At nanoscale, electrons behave like waves, allowing them to pass through solid objects using a technique called tunnelling.

The atomic force microscope worked in a similar way, but used a silicone tip and a laser to trace the surface of a sample. It could tell researchers about the magnetic, electrical, chemical and physical properties of materials they could never hope to see with their own eyes.

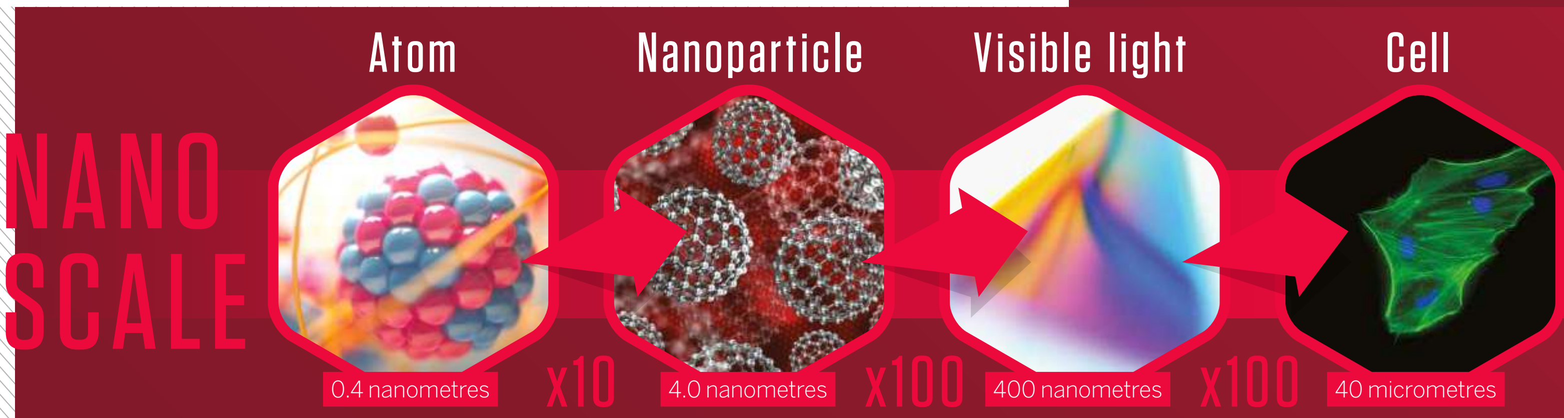
By the 1990s the field had exploded. Researchers observed carbon nanotubes for the first time – just a single atom thick, they were stronger than steel. In the years that followed, scientists developed the ability to fold DNA like paper, and they discovered that it was possible to guide nanoparticles inside the body like homing missiles. Now, with science advancing at lightning speed, Feynman's dreams are closer than ever.

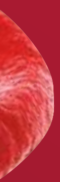


Organs-on-chips use nanotechnology to simulate parts of the human body



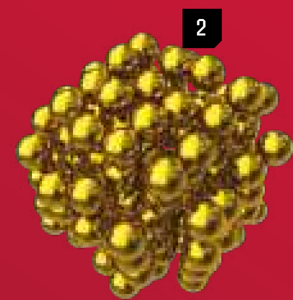
IBM invented the world's first circuit-based commercial quantum computer

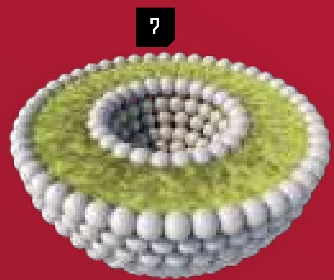


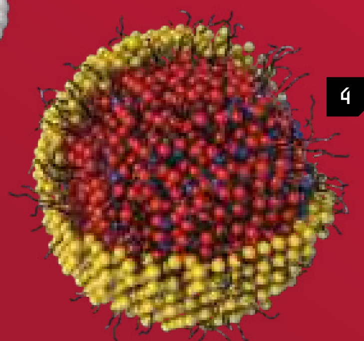


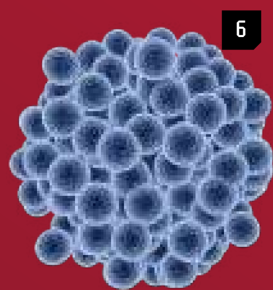
TYPES OF NANOMATERIALS

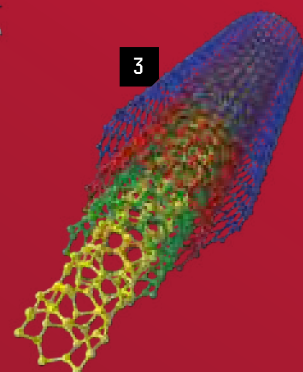
Each of these small-scale particles has the potential to change the world

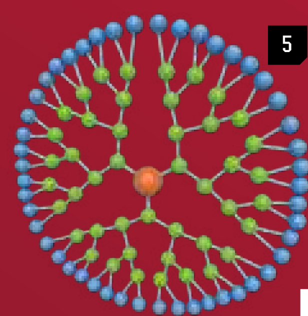












1 MICELLE
These self-assembling structures have an outer water-loving shell and an inner water-hating core. They can help stubborn chemicals dissolve by shielding them from water, potentially aiding drug delivery.

2 GOLD
Made from an inert precious metal, these nanoparticles show promise in medical treatment. They can carry chemicals and genetic material to precise locations inside the body without causing any harm.

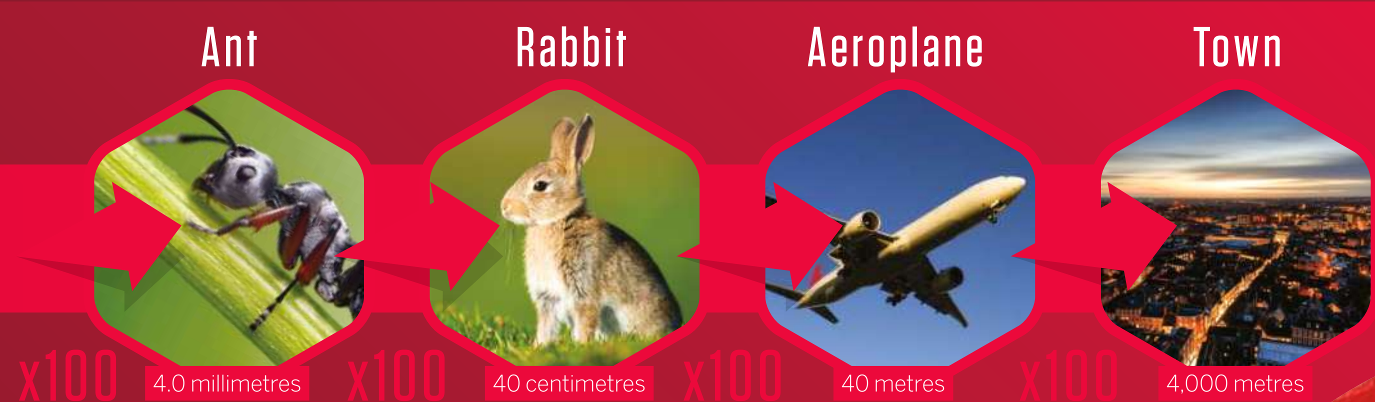
3 CARBON NANOTUBE
These large-scale nanoparticles form hollow rods one atom thick and with a tensile strength greater than steel. They have potential applications in everything from display screens to artificial limbs.

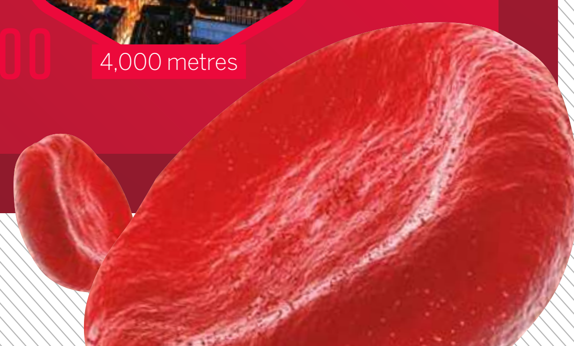
4 QUANTUM DOT
Also known as artificial atoms, these nanoparticles have a crystal structure. They are tiny semiconductors with the ability to absorb photons and emit light, making them attractive for display technology.

5 DENDRIMER
These symmetrical nanoparticles have arms that look a bit like the branches of trees. They can carry molecules inside their cores, making them a possible delivery vehicle for cancer treatments.

6 MAGNETIC
Made from iron oxide, these nanoparticles have all the properties of a full-sized magnetic material. They show promise in medical diagnosis and treatment because magnets can guide them into position.

7 LIPOSOME
These little spheres can carry cargo into living cells. Made from cholesterol and fats called phospholipids, they could help deliver drugs that wouldn't normally be able to cross the cell membrane.



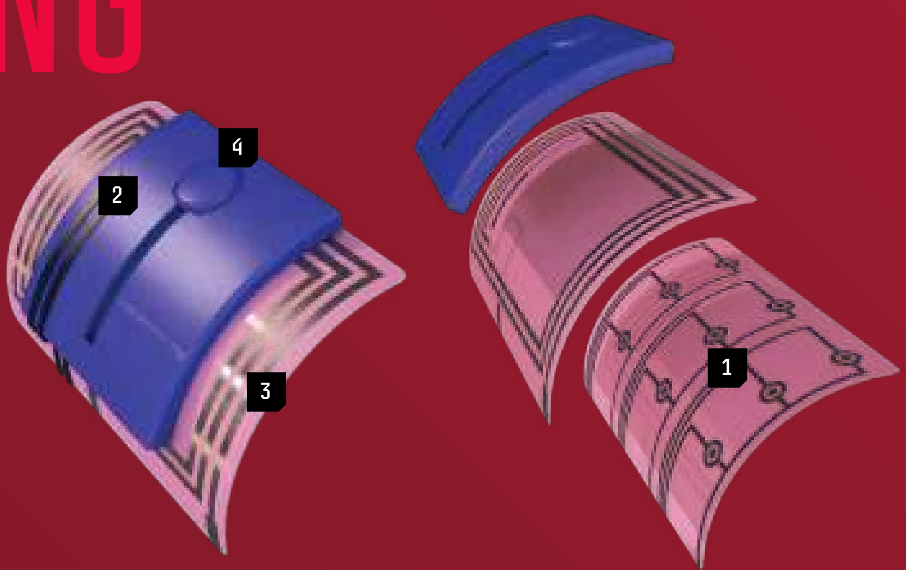


Cell-sized robots could revolutionise medical diagnosis and treatment

INTRODUCING NANOBOTS

Nanobots are robots on a molecular scale. Smaller than a grain of sand, these programmable particles take inspiration from biology. Inside every living cell are tiny machines that are surprisingly like the machines we use in our everyday lives. There are pumps, motors, switches and even clocks, all working together to perform complex work in miniature. Researchers have taken inspiration from these machines to create brand-new technology from tiny component parts. Made from proteins, fat and even DNA, nanobots have the potential to perform tasks like delivering drugs, killing bacteria and inactivating toxins. Some of the most promising use a design pattern called DNA origami. Made from repeating units of genetic code, these tiny particles can self-assemble into geometric shapes. They can form hollow cubes, rod-like scaffolding and even gears. In the future, particles like these could recreate mechanical machines on a nanoscale.

Did you know?
Metal nanoparticles can kill microbes on contact



WEARABLE NANOPATCHES

Skin-mounted sensors can detect deadly gases, monitor the body or deliver life-saving drugs

1 SENSOR ARRAY
Miniature sensors can detect anything from touch and temperature to chemicals in the air.

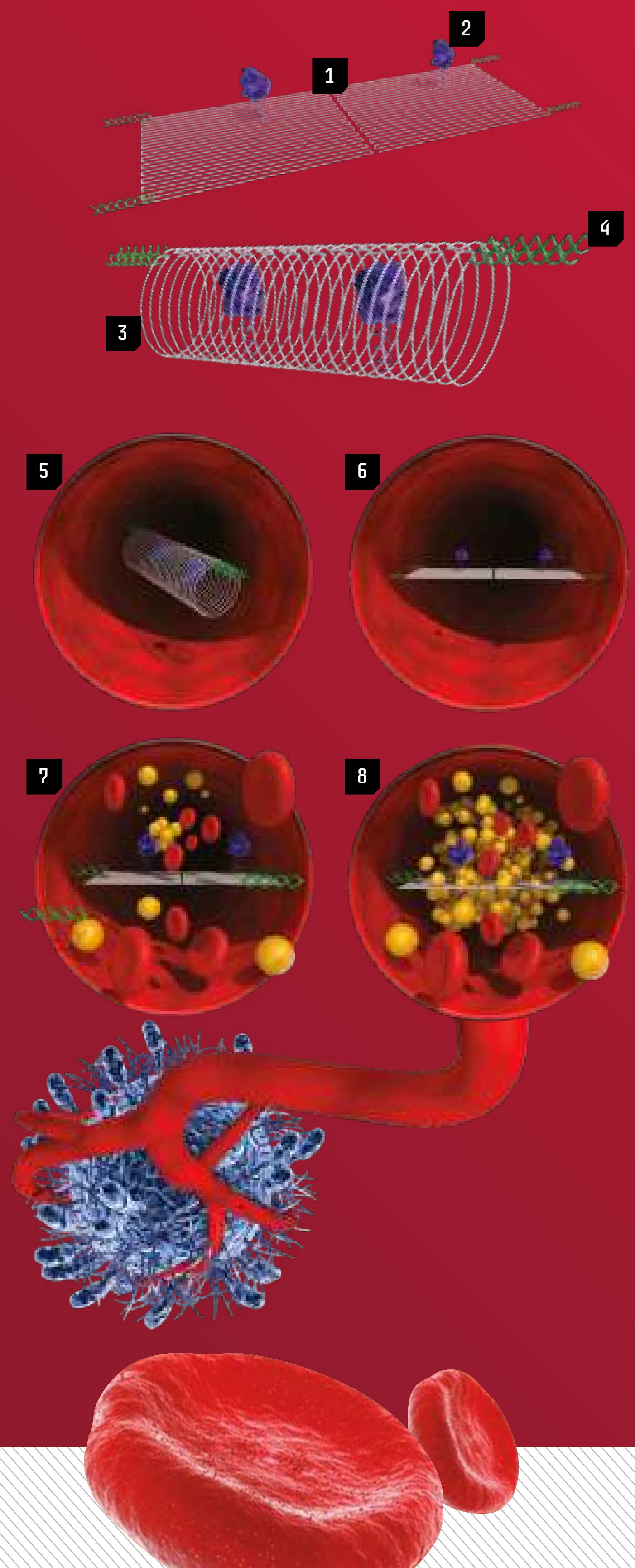
2 FLEXIBLE MATERIALS
Nanomaterials mixed with fabrics or polymers create flexible sheets that can move with the body.

3 SELF-POWERED
Nanogenerators harvest electricity from friction, heat, sound, vibration and even wind or blood flow.

4 DRUG DELIVERY
Patch-mounted pumps can deliver life-saving treatments, like insulin for diabetes.

FIGHTING CANCER WITH NANOBOTS

Miniature robots from Arizona State University destroy tumours by cutting off their blood supply



1 DNA SHEETS
Flat, rectangular sheets of DNA form the basic scaffolding of the nanobots.

2 THROMBIN
The sheets carry a protein called thrombin, which causes blood to clot.

3 ORIGAMI
The DNA folds over to form a tube around the thrombin.

4 HOMING SIGNAL
Fragments of DNA at the edges of the sheet guide the nanobots to molecules found on the surface of cancer cells.

5 INSIDE THE BODY
Each nanobot measures just 60 nanometres in length, allowing it to fit easily into tiny blood vessels.

6 TROJAN HORSE
When the nanobots reach the tumour they uncurl, revealing the thrombin proteins hidden inside.

7 CLOTTING BEGINS
The blood starts to clot around the nanobots, sticking together to form a solid plug.

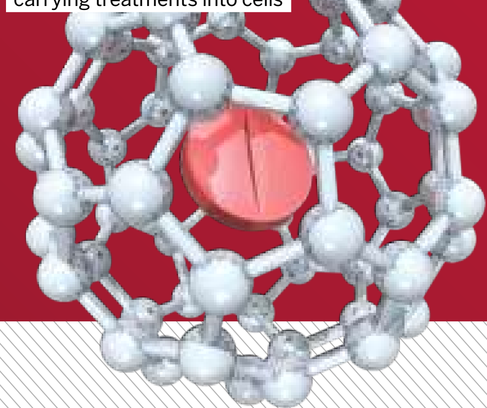
8 TISSUE DAMAGE
Within 24 hours, the clot blocks the blood supply to the tumour, killing the cancer cells.

NANODENTISTRY

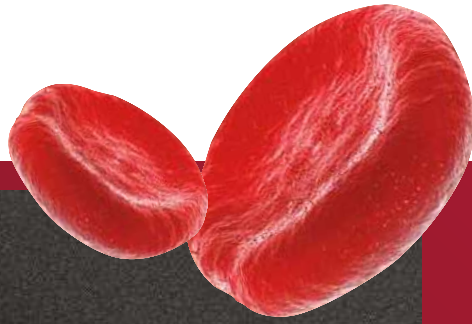
Nanobots have the potential to revolutionise dentistry. Performing surgery in the mouth is difficult. There isn't a lot of room to move around, and there are lots of vital tissues, nerves and blood vessels close together. In the future, nanobots could travel through the gums and deliver anaesthetic directly to an individual tooth, without the need for needles. They could use nanoparticles made from the bone mineral hydroxyapatite to repair cavities and jaw damage. And they could even destroy harmful bacteria. Future nanodentistry could also include high-tech mouthwash or toothpaste to deliver a protective nanocoating to shield teeth from plaque and tartar.

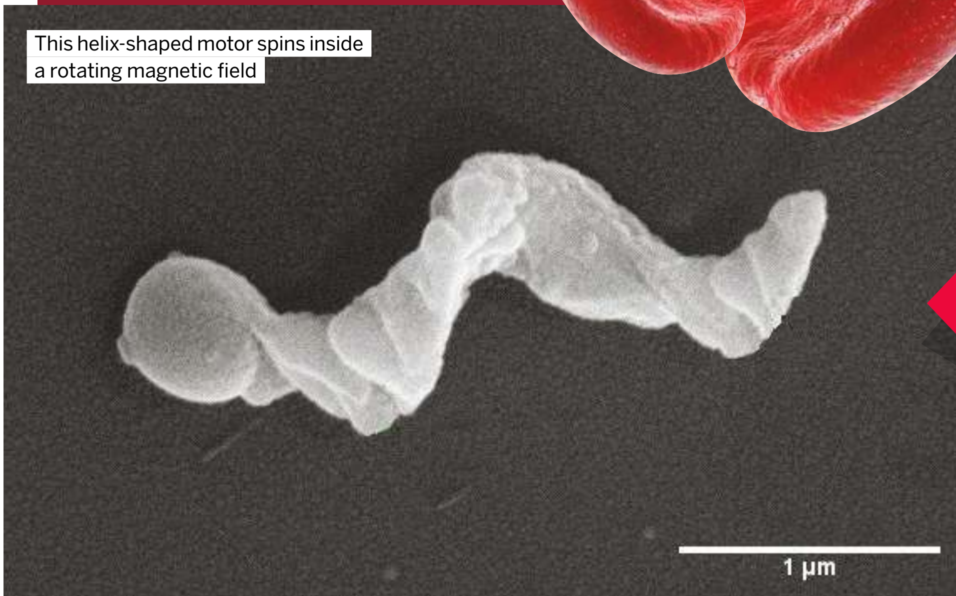
Nanotechnology could make dentistry painless and precise in the future

Electrospun nanofibres could make ultra-fine virus filters for masks



Nanoparticles work like Trojan horses, carrying treatments into cells





This helix-shaped motor spins inside a rotating magnetic field

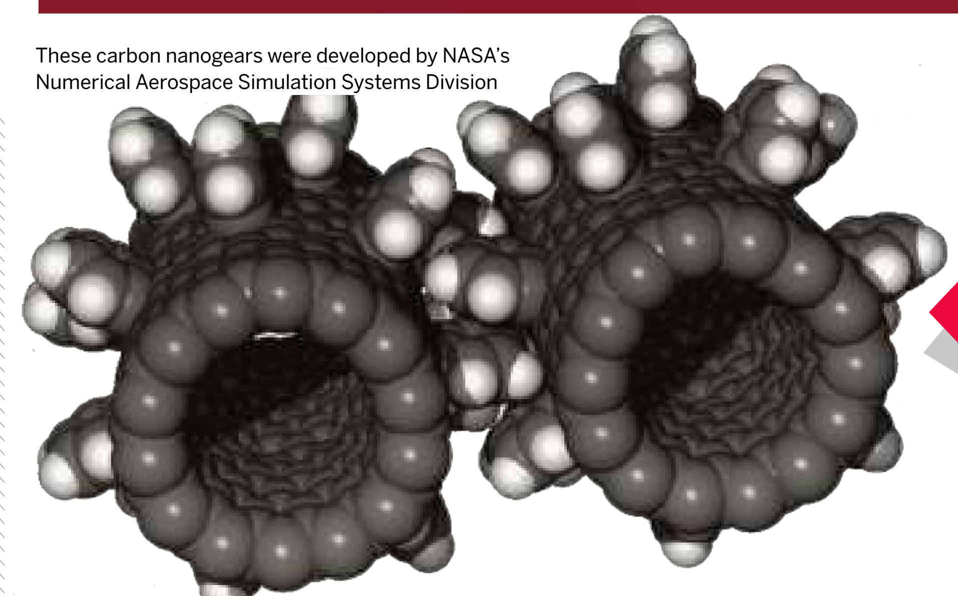
MAGNETIC NANOBOTS

Magnetic nanoparticles respond to external magnetic fields. This makes it possible to guide them through space, opening the way for magnet-driven nanobots. Researchers have found that applying different types of magnetic fields can make the tiny robots move in different ways. A rotating magnetic field can make a helical robot spin, winding forward like spring. An oscillating magnetic field can make a nanobot undulate, curling up and down like a fish. And a stepping magnetic field can make it stop and start like a switch, allowing a nanobot's limbs to perform rowing movements. It's also possible to combine magnetic control with other types of input, like light or ultrasound. This could one day allow much finer control of a nanobot's movement, allowing it to perform highly complex and extremely delicate tasks, like surgery.

DNA-sized transistors like those on this silicon wafer could one day allow computers to fit inside cells

ULTRA-POWERFUL COMPUTERS

Computers think in zeros and ones. They contain millions of tiny switches, called transistors, that can be either on (one) or off (zero). The more transistors a computer has, the faster it can think. For the past few decades, engineers have been working hard to make this technology as small as possible. As a result, the number of transistors that can fit on a computer chip has roughly doubled every two years – a phenomenon known as Moore's law. Your average computer now contains transistors no bigger than 14 nanometres across, while the most advanced contain transistors that measure just seven nanometres. In 2022, IBM unveiled transistors that measure just two nanometres, thinner than a strand of DNA, making it possible to pack 50 billion onto a chip the size of your fingernail.



These carbon nanogears were developed by NASA's Numerical Aerospace Simulation Systems Division

FULLERENE MACHINES

In 2016, three chemists received the Nobel Prize for developing the world's smallest machines. They had invented chains, axles and motors on a molecular scale. These advances led to the development of the world's first nanocar in 2005, a moving vehicle 20,000 times smaller than the width of a human hair. The car had wheels made from buckyballs and axles that moved freely, allowing the whole structure to roll. By 2017, researchers were literally racing to develop the next generation of nanoautomobiles. The world's first nanocar race was held in France, using a scanning tunnelling microscope to propel six of the world's smallest cars towards the finish line. These experiments are good for more than just entertainment, however. They could one day lead to programmable machines capable of performing mechanical work on a miniature scale.

DID YOU KNOW? In 1990, IBM engineers carefully positioned 35 xenon atoms to spell out the company logo on a nanoscale

5 FACTS
NANOTECH THAT ALREADY EXISTS

1 COMPUTER PROCESSORS
The processor that powers your computer or your phone contains hundreds of tiny switches called transistors. Each one measures less than ten nanometres across.

2 QUANTUM DISPLAYS
Ultra-high-definition QLED screens contain tiny nanocrystals called quantum dots – the Q in QLED stands for quantum. They contain nanoscale semiconductors that emit different coloured light depending on their size.

3 MOLECULAR PRINTERS
It's now possible to 3D print at nanoscale using an AI-powered scanning tunnelling microscope. The powerful piece of kit can pick up and lay down molecular building blocks.

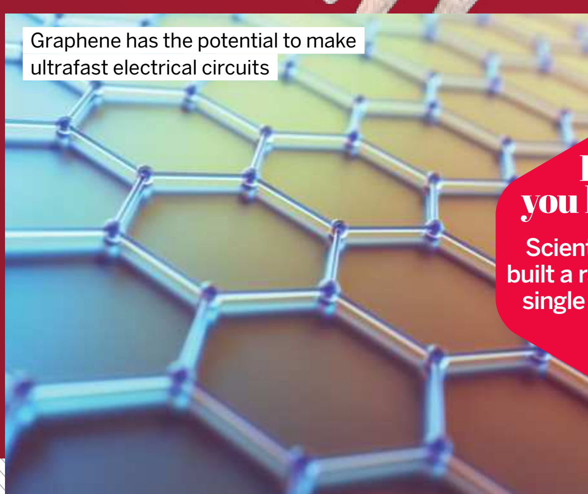
4 FLEXIBLE SCREENS
Advances in nanotechnology have made it possible to bend, roll and even fold electronic screens. They use flexible plastic polymers and ultrafine conductive materials like graphene or silver nanowires.

5 SELF-HEALING PLASTIC
New types of plastic combine flexible paint-like materials with tough nanoscale polymers to allow tears and breaks to self-heal. The process even works under water.

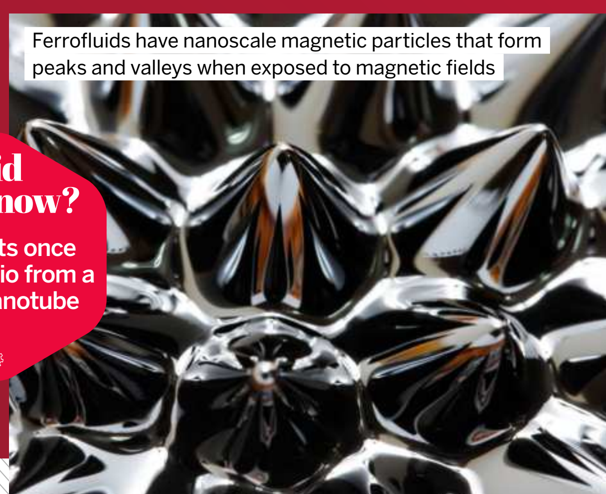
FLEXIBLE NANOTECH

Sheet materials just one atom thick have the potential to become anything from bendy screens to e-tattoos

"A rotating magnetic field can make a helical robot spin"



Graphene has the potential to make ultrafast electrical circuits



Ferrofluids have nanoscale magnetic particles that form peaks and valleys when exposed to magnetic fields

Did you know?
Scientists once built a radio from a single nanotube

TECHNOLOGY

INSIDE THE ATARI 2600

This groundbreaking console spawned a new era of home entertainment

WORDS **MARK SMITH**

It's hard to imagine now, but this little black box was a trailblazing piece of technology, giving rise to the games consoles we know and play today. Atari, founded in 1972, was among the first video game companies, and produced *Pong*, the first successful arcade game. In the early 1970s, video games had become popular in amusement arcades, but the idea of having them at home was pretty unusual. But that was about to change. Fairchild Camera and Instrument introduced the Channel F system, the first cartridge-based home video game system, in 1976, and in 1977 Atari launched the Video Computer System (VCS), which would later be renamed the 2600.

Unlike early home computers, which were designed mainly for practical purposes such as word processing, consoles were all about fun. The 2600 was designed to be plugged straight into the TV, and the games had no loading times. Primitive by today's standards, it boasted a 1.19MHz 8-bit processor, 128 bytes of RAM and two-channel mono sound, and retailed for $199 – equivalent to $849 today, or about £615. Although there were only nine games available when it was launched, it quickly came to dominate the fledgling industry, selling over 30 million units and hundreds of millions of games.

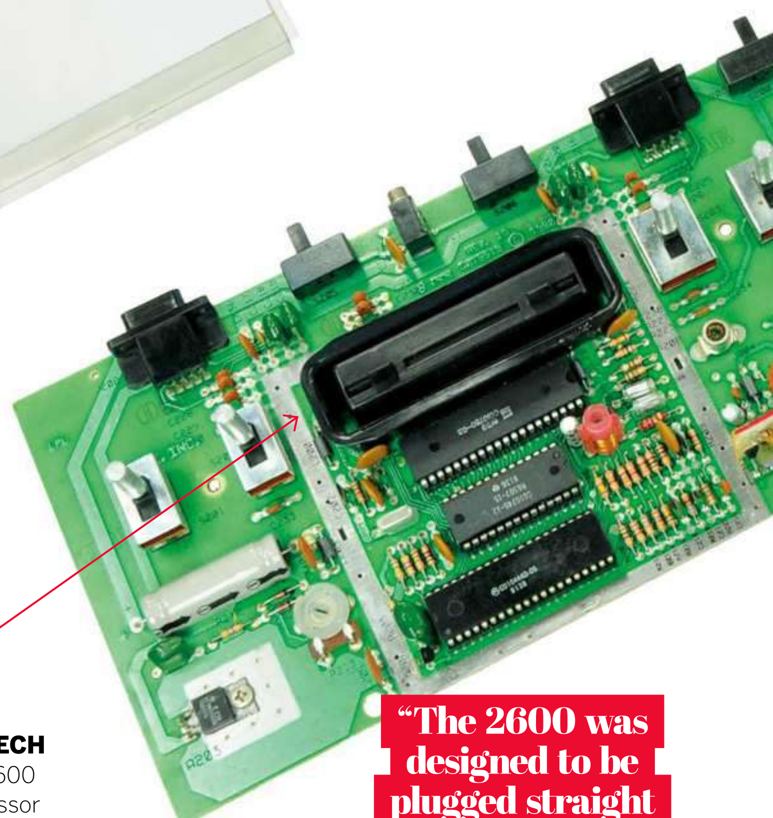
In the 1980s the console cemented its place as a must-have piece of home entertainment gear with the release of the iconic *Space Invaders*. The game was so popular that people were buying the console just to play that one game. Today the Atari 2600 still has a large number of fans, with some games still being produced today by hobbyist developers.

UNDER THE COVER

The early console was packed with then-revolutionary home technology

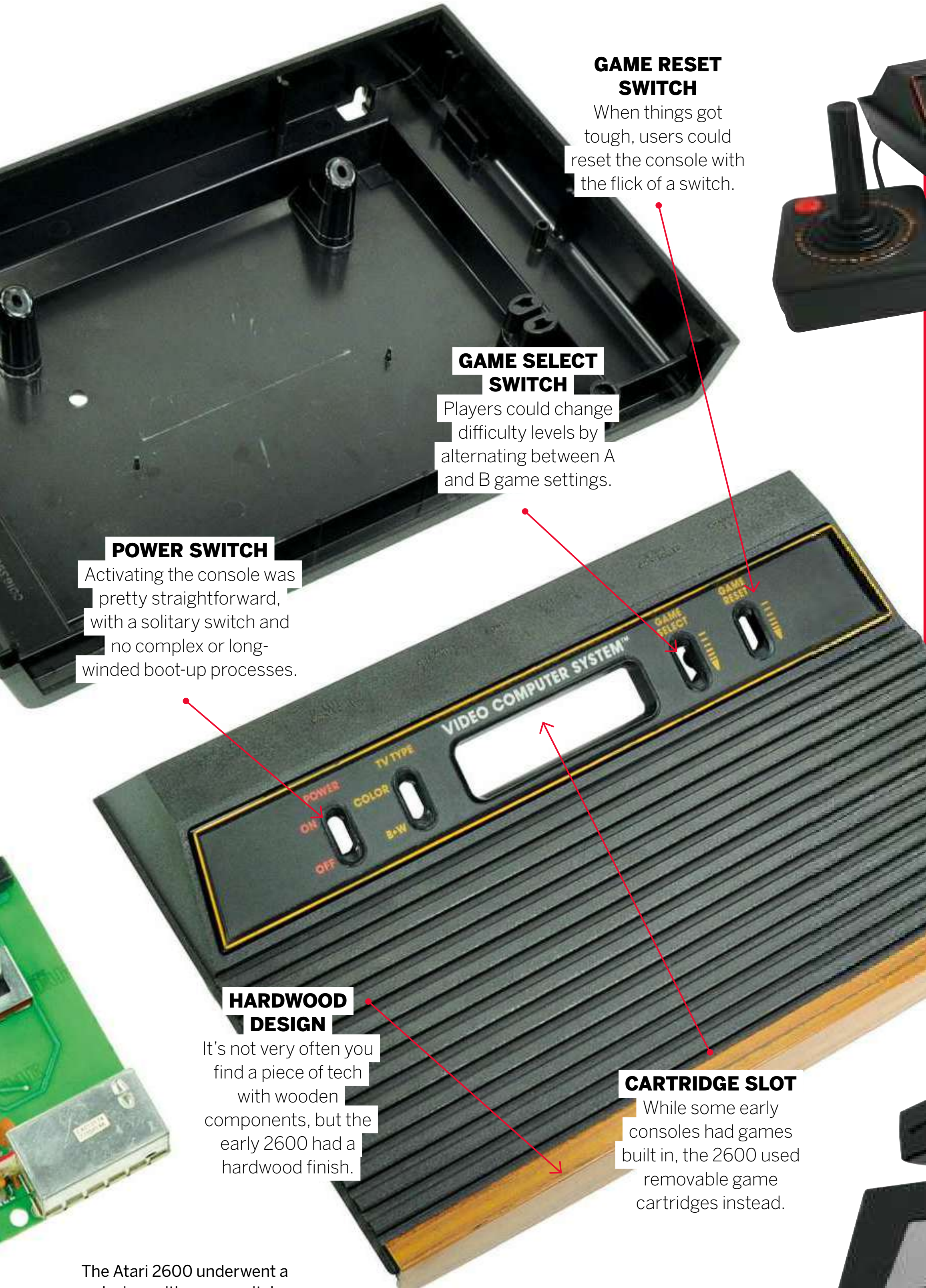
TV CONNECTOR LEAD
There was no need for a monitor. By using this lead, any TV could be used to display the games on screen.

METAL PROTECTION
A metal box fitted between the circuit board and case ensured the console was pretty robust.



MICROPROCESSOR TECH
The circuit board of the 2600 was based on microprocessor technology – the company's first venture in the field.

> "The 2600 was designed to be plugged straight into the TV"



GAME RESET SWITCH
When things got tough, users could reset the console with the flick of a switch.

GAME SELECT SWITCH
Players could change difficulty levels by alternating between A and B game settings.

POWER SWITCH
Activating the console was pretty straightforward, with a solitary switch and no complex or long-winded boot-up processes.

HARDWOOD DESIGN
It's not very often you find a piece of tech with wooden components, but the early 2600 had a hardwood finish.

CARTRIDGE SLOT
While some early consoles had games built in, the 2600 used removable game cartridges instead.

WHAT WAS IN THE BOX?

The first VCS units came with everything a person needed to start playing straight out of the box: two joysticks, a single pair of paddles and the two-player *Combat Cartridge*, which contained several tank and plane action games. Unlike the big launches of today, there weren't a whole lot of games available when it first hit the shelves. Besides the *Combat Cartridge*, there were just eight other game titles available at launch. A few of them were based loosely on Atari's popular arcade games. The games available were *Air-Sea Battle*, *Basic Math*, *Blackjack*, *Indy 500*, *Star Ship*, *Street Racer*, *Surround* and *Video Olympics*.

The console was unusual since it used cartridge-based technology rather than built-in games

The Atari 2600 underwent a redesign, with some switches moved to the back of the console

HOW PET ID TAGS WORK

These smart devices reunite owners with their animal companions


Small microchips implanted under a pet's skin can be scanned to display digital information about an animal and its owner

WORDS **AILSA HARVEY**

No matter how much an owner adores their pet and takes precautions to keep them safe, it's still very common for animals to go missing. When this happens, it can be distressing for both pet and owner. Some of the main reasons for a pet getting lost include fear or anxiety, curiosity, hunting and mating instincts.

An owner only has to look away for a short time before completely losing track of their pet. Even if they spot them chasing something into the distance, dogs are often much faster than their owners, leaving them helpless. Meanwhile, cats, which don't require supervision and typically do their own thing, may leave an area they know well and struggle to return home.

Pet identification (ID) tags are worn by domestic animals to reunite lost pets with their owners. These tags display contact information and other important details about the animal. Without these, if a stranger finds a wandering animal, they have no way of knowing whether it's a loved and sought-after pet or a stray.

Keeping your pet's name and your contact information secured to your pet's collar enables others to inform you of your animal's whereabouts. But for those wanting to take a more active role in the search, tracking tags prevent owners from having to helplessly wait for news. These smart tags vary in range, but some can provide digital information about an animal's whereabouts and live tracking details as soon as a pet is lost.


This dog is wearing a GPS tracker around its neck

DID YOU KNOW? Some smart tags instantly alert animal shelters and rescue groups within a set radius of a pet's last known location

QR stands for 'quick response'

DIGITAL PROFILE

Some pet collars display a QR code instead of written information. These need to be scanned by a smartphone camera. Today many people carry their phones with them everywhere, so reporting sightings of animals that appear lost is quicker and easier than ever. Using QR codes means that more details about a pet – such as contact details, medical information and photographs – can be stored in a small space on the ID tag. As long as the person who finds the missing animal has a smartphone and access to the internet, when they scan the QR code, they will get instant access to this helpful information.

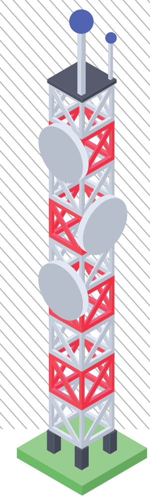
When the collar tag is scanned, the phone screen will display the animal's profile. This can store multiple emergency contact numbers in one place to ensure that the person who has found your pet will be able to get into contact with someone. Digital tags are also more flexible, as owners can change their details online. This feature means details can also be temporarily changed – to a pet sitter's, for example – when the owners are elsewhere. Without this flexibility, a lost or broken phone could reduce the chances of an owner seeing their pet again.

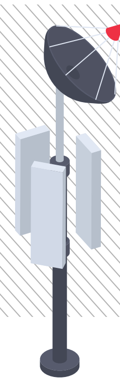
Did you know?

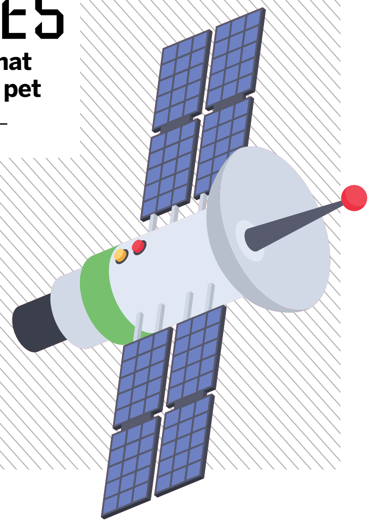
12 to 18 per cent of cats go missing at least once in a five-year period

TRACKER TYPES

There are three main systems that can be used to track down a lost pet







RADIO

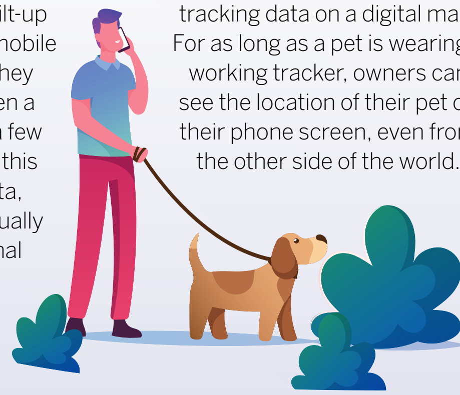
Radio frequencies can be used to locate a missing pet. Signals are released from the animal's collar and picked up by the owner's transmitter. On the screen, the direction and distance are displayed. These trackers are relatively bulky, and so can't be used easily on small animals. They are used across short distances and require the owner to be able to travel to their pet.

CELLULAR

These use mobile phone masts to retrieve an animal's location. Cellular trackers are most beneficial in built-up areas with good mobile phone signals. They are accurate when a pet is lost within a few street blocks. As this uses mobile data, these trackers usually have an additional monthly cost.

GPS

Using satellites to locate an animal's whereabouts, GPS trackers can show owners live tracking data on a digital map. For as long as a pet is wearing a working tracker, owners can see the location of their pet on their phone screen, even from the other side of the world.



DO ALL DOGS NEED TAGS?

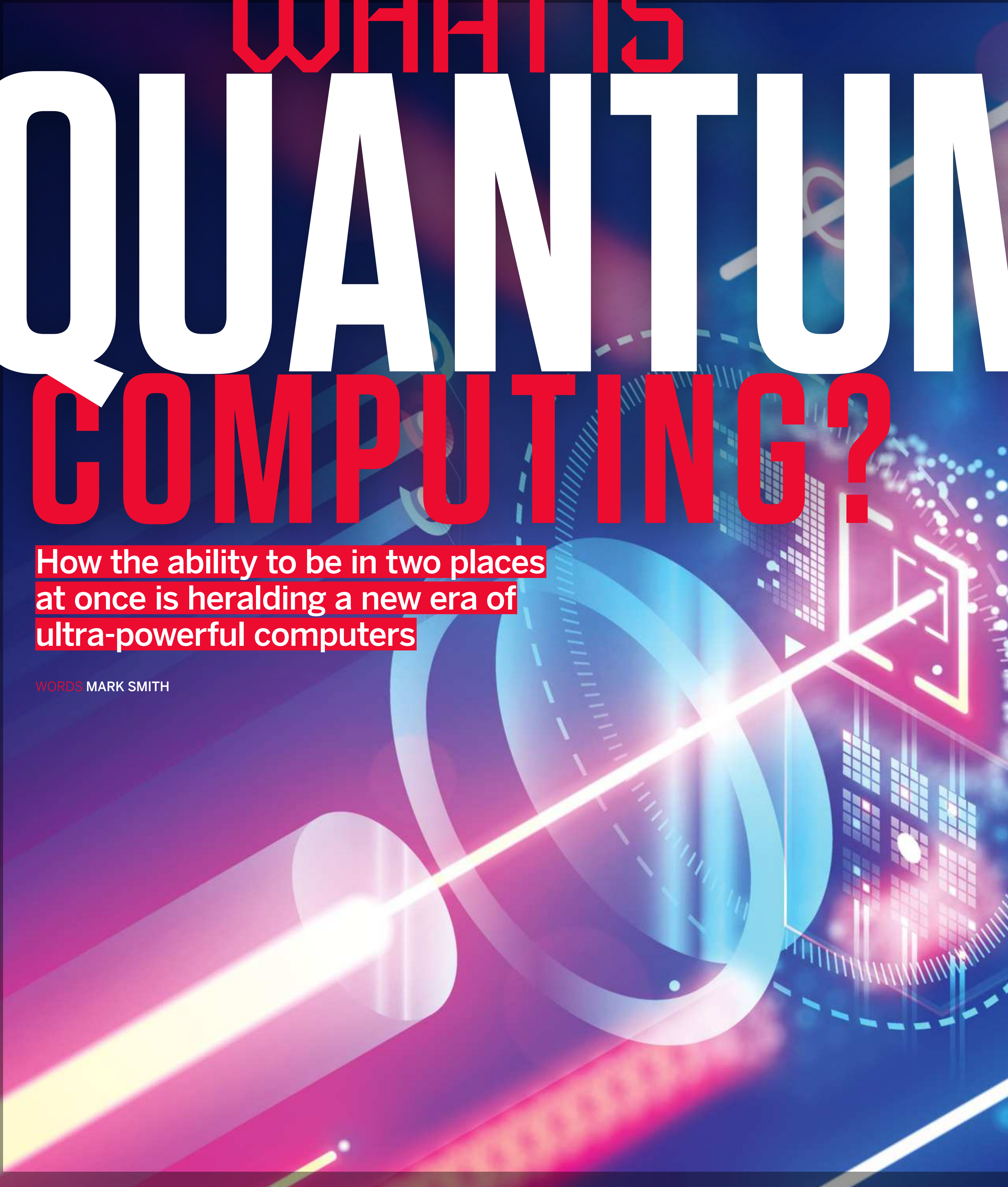
It's illegal in many countries, such as the UK, US, Canada and Australia, for dogs to be walked in public without an ID tag on their collar. In the UK these tags must include at least a name and address, otherwise dog owners can receive a fine of up to £5,000 ($6,550). There are some exceptions to this law. In UK legislation, this includes dogs used for sport, to control cattle and sheep, for emergency or rescue purposes and guide dogs. All dog owners should check the law in their local area, because these laws can vary by country or regions of the same country.

Guide dogs don't always require ID tags, but many owners choose to take this precaution

WHAT IS QUANTUM COMPUTING?

How the ability to be in two places at once is heralding a new era of ultra-powerful computers

WORDS MARK SMITH



DID YOU KNOW? The first dedicated quantum computer for business, 1QBit, was unveiled in 2012 in Vancouver, British Columbia

Imagine a new type of computer 158 million times faster than the most sophisticated supercomputer we have in the world today. A device so powerful that it could do in four minutes what it would take a traditional supercomputer 10,000 years to accomplish. This is the promise of new technology known as quantum computing.

For decades our computers have all been built loosely around the same design. Whether it's the huge machines at NASA or your laptop at home, they are all essentially just glorified calculators, and crucially they can only do one thing at a time. The key to the way all computers work is that they process and store information made of binary digits, called bits. These bits only have two possible values: a one or a zero. It's these numbers that create binary code, which a computer needs to read in order to carry out a specific task. But this is where quantum computing changes things.

This is because they use a branch of physics known as quantum theory, which deals in the tiny world of atoms and the subatomic particles inside them. When you delve into this minuscule world, the laws of physics are very different to what we see around us. For instance, quantum particles can exist in multiple states at the same time – this is known as superposition. Instead of bits, quantum computers use something called quantum bits, or 'qubits' for short. But here is the magic part... while a traditional bit can only be a one or a zero, a qubit can be a one, a zero or it can be both at the same time.

So what does this mean? Essentially, it means a quantum computer doesn't have to wait for one process to end before it can begin another; it can do them at the same time. Think of it this way: imagine you had lots of doors that were all locked except for one, and you needed to find out which one was open. A traditional computer would keep trying each door, one after the other, until it found the one which was unlocked. It might take five minutes, or it might take a million years, all depending on

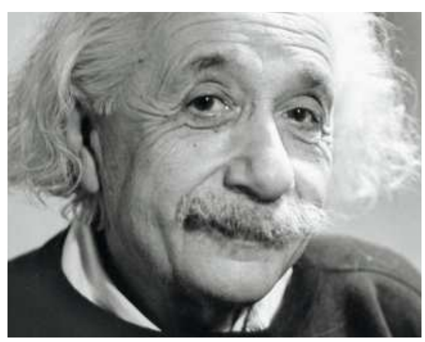
Did you know?
The Sa 30 qubit can run trillions of operations per second

WHY DO WE NEED QUANTUM COMPUTING?

In some ways, standard computers are pretty dumb. They can do what they are told to do well enough if they are fed the right computer program by a human. But when it comes to predicting things? Not so smart. This is why the weather forecast isn't always right. There are too many variables – too many things changing too quickly for any conventional computer to keep up.

Because of their limitations, there are some computations that an ordinary computer may never be able to solve, and others that might take it a billion years. Not much good if you need a quick prediction or piece of analysis. But a quantum computer is so fast – seemingly infinitely so – that it could respond to changing information quickly and examine a limitless number of outcomes and permutations simultaneously.

Quantum computers are also relatively small because they don't rely on transistors like traditional machines. They also consume comparatively less power, meaning they could be better for the environment.



Even the great Albert Einstein was bamboozled by quantum behaviour

how many doors there were. But a quantum computer could try all the doors at once. This is what makes them so much faster. As well as superposition, quantum particles also exhibit another strange behaviour called entanglement, which makes this tech potentially groundbreaking.

As well as speed, another advantage they have over traditional computers is size. According to Moore's law, computing power doubles roughly every two years. But in order to enable this, engineers have to fit more and more transistors onto a circuit board. A transistor is like a microscopic light switch that can be either off or on. This is how a computer processes the zeros and ones that you find in binary code.

But to solve more complex problems, you need more of those transistors. But no matter how small you make them, there's only so many you can fit onto a circuit board. Sooner or later, traditional computers are going to be as smart as we can possibly make them. That is where quantum machines can change things.

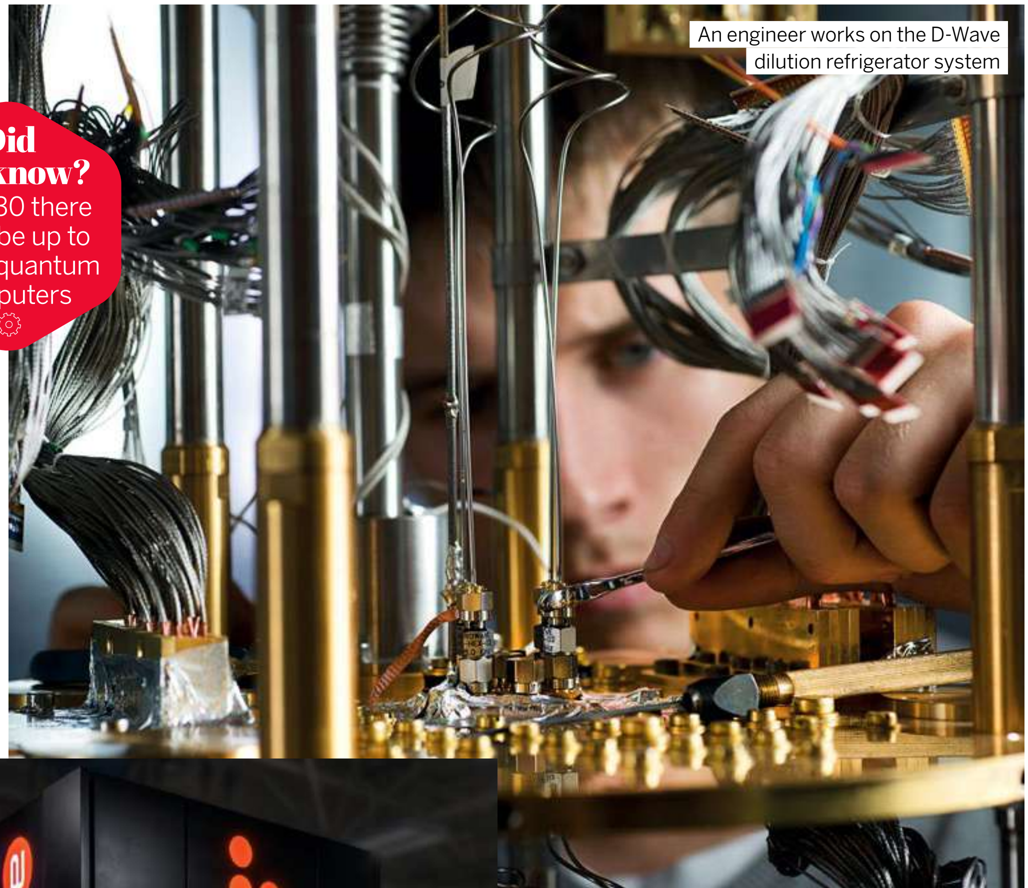
The quest to build powerful quantum computers has turned into something of a global race, with some of the biggest companies – and indeed even governments – on the planet vying to push the technology ever further, prompting a rise in interest in quantum computing stocks on the money markets. One prime example is a device created by D-Wave Systems. The Canadian company has built the Advantage system, which it says is the first and only quantum computer designed for business use. The company says it has been designed with a new processor architecture with over 5,000 qubits and 15-way qubit connectivity, allowing companies to solve their largest and most complex business problems.

D-Wave Systems says it is the first quantum computer that enables customers to develop and run real-world, in-production quantum applications at scale in the cloud. The Advantage is 30 times faster and delivers equal or better solutions 94 per cent of the time compared to its previous-generation system.

But despite the huge theoretical computational power of quantum computers, there's no need to consign your old laptop to the bin just yet. Conventional computers will still have a role to play in any new era, and are far more suited to everyday tasks such as browsing the internet, spreadsheets, emailing and word processing.

Where quantum computing could really bring about radical change, though, is in predictive analytics. Because a quantum computer can make analyses and predictions at breakneck speeds, it could perform fast traffic modelling and make far more accurate weather forecasts – things where there are millions if not billions of variables that are constantly changing.

Did you know?
By 2030 there could be up to 5,000 quantum computers



An engineer works on the D-Wave dilution refrigerator system

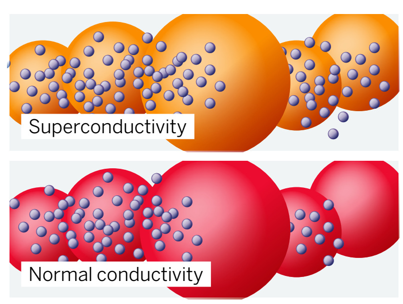
The D-Wave Advantage is said to be the world's first quantum computer for business

"A quantum computer can make analyses and predictions at breakneck speeds"

PERPETUAL ENERGY

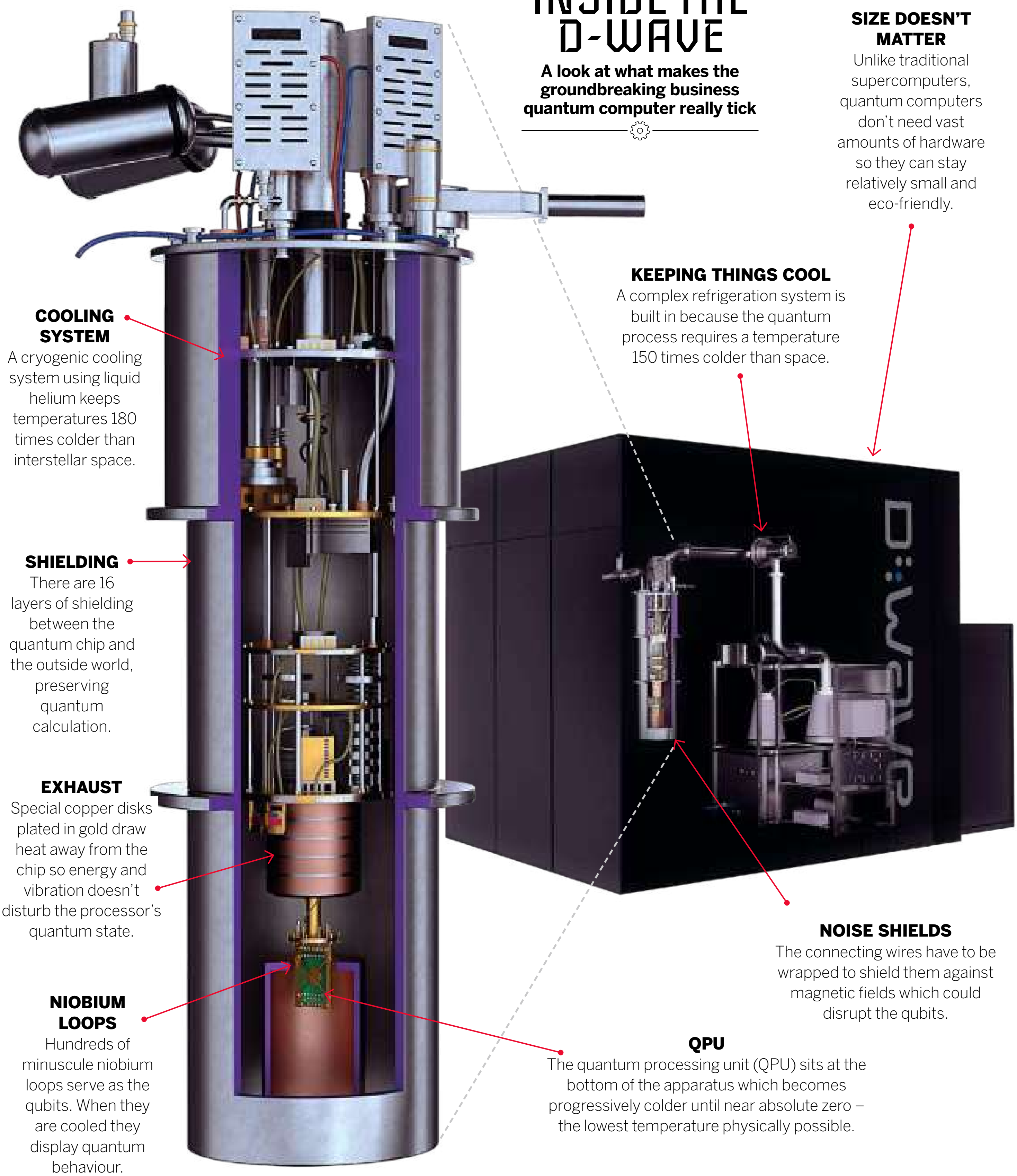
One of the challenges for quantum computing is that qubits are super sensitive. In order for them to be usable they have to remain in their quantum state, but this is easily disrupted by coming into contact with heat, electromagnetic fields or collisions with air molecules. Superconductors are the answer. But even with a good conductor, some charge is still lost due to resistance.

Because superconducting materials operate according to the bizarre rules of the quantum realm, they don't have any resistance, allowing a charge to flow through them without any of it dissipating and creating an endless flow of charge that doesn't disrupt the qubits.



INSIDE THE D-WAVE

A look at what makes the groundbreaking business quantum computer really tick

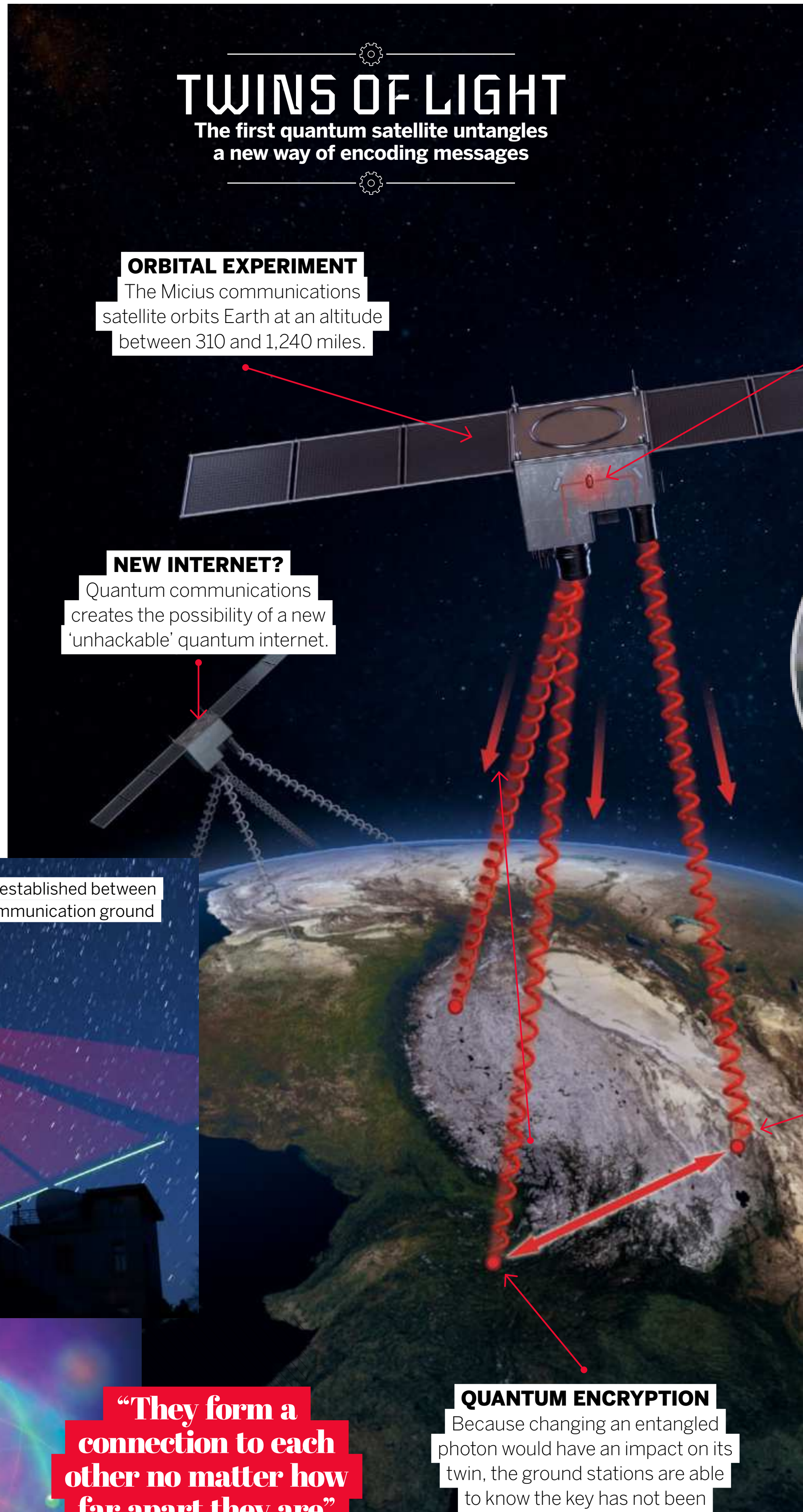


DAWN OF A NEW ERA

Where quantum computers could really come into their own is where possible outcomes have to be calculated in huge numbers and at great speed. For example, predicting the flow of traffic through a huge city would be difficult for a standard computer because of all the data it would have to crunch – from roadworks and road layout to the day of the week, and even things like daylight and cloud cover. Other uses include weather and financial predictions, encryption, communications and cyber security.

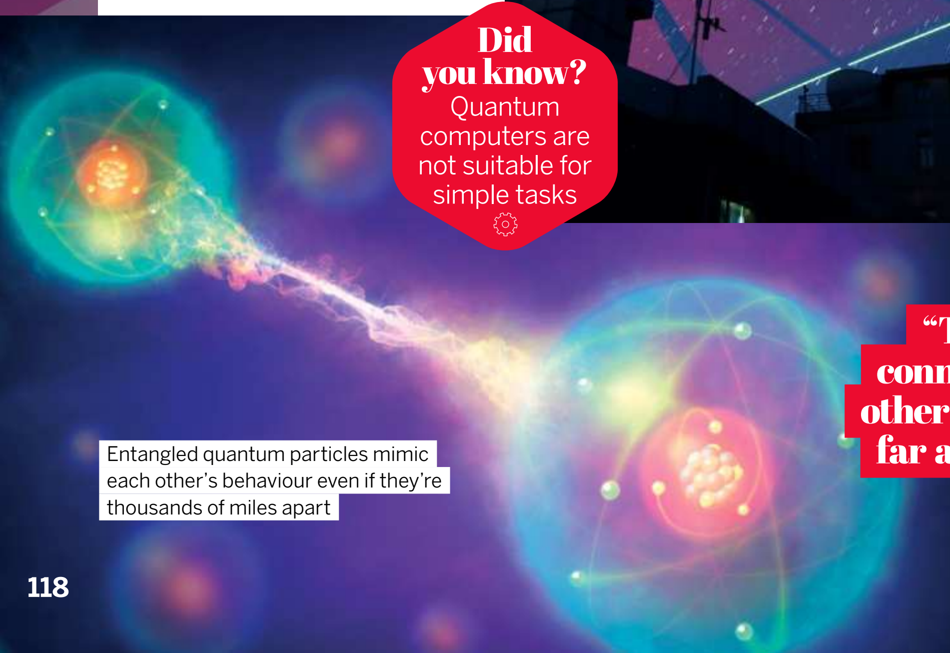
The Chinese quantum satellite Micius was launched in 2016, serving as a trailblazer for the real-world application of quantum communications technology. Named after an ancient Chinese philosopher, it harnessed another quirky quantum behaviour known as entanglement. When two quantum particles are entangled, they form a connection to each other no matter how far apart they are. When you alter one, the other responds the same way – even if they're thousands of miles apart. Einstein called this particle property 'spooky action at a distance'. Using this entanglement process, scientists on the project were able to create a key to encode a message which could only be decoded using the other 'twin'.

In 2017, Micius was used to distribute quantum cryptographic keys to ground stations near Vienna and Beijing, enabling a secure virtual meeting between the Austrian and Chinese science academies, which were 4,600 miles apart. It's this type of technology that's opening up a whole new field of uncrackable communication which would allow messages to be passed away from eavesdroppers, be they rival governments and corporations or cyber criminals.




A satellite-to-Earth link was established between Micius and the quantum communication ground station in Xinglong

Did you know? Quantum computers are not suitable for simple tasks

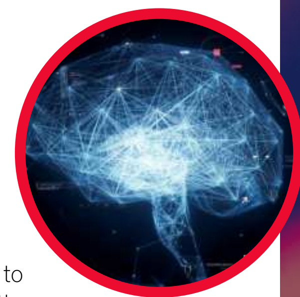

Entangled quantum particles mimic each other's behaviour even if they're thousands of miles apart

> "They form a connection to each other no matter how far apart they are"

DID YOU KNOW? The D-Wave 2000Q system operates at 0.015 Kelvin, 180 times colder than interstellar space

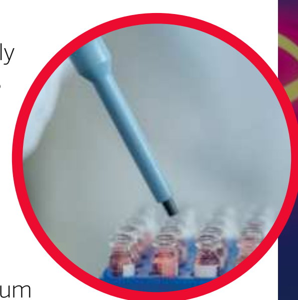
USES FOR QUANTUM COMPUTING

MAKING AI SMARTER



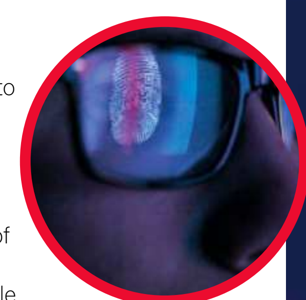
As well as quantum computing, another rapidly developing field is artificial intelligence (AI). But in order for the industry to grow, new ways need to be found to 'train' AI at speed. This is because for AI to learn, it has to take in lots of information. In theory, it could crunch numbers for 1,000 years to learn enough information in order for it to make its own decisions. But with quantum computing, AI could learn the same amount of information in a matter of seconds.

CREATING NEW DRUGS



Crafting new treatments and pharmaceuticals can be a costly and time-consuming task. This is because at its most fundamental level, this type of scientific endeavour is all about trial and error. Scientists have to craft a new drug, test it, take the test data and begin all over again. Quantum computing could streamline that entire process. Scientists believe these types of advancements in quantum computing could make things a whole lot more efficient because simulations could be run and rerun at speed, with infinite permutations examined. This would also enhance safety and cost effectiveness.

CYBER SECURITY



The more we live our lives online, the more we're open to cyber attacks. But quantum computing could create a new generation of impenetrable cyber defences. The sheer power of quantum computers means they could create uncrackable codes that no traditional hacker could penetrate. Quantum-era cybersecurity will also have the power to detect and deflect cyber attacks before they cause problems. The other side of the coin, though, is that a quantum computer in the hands of a hacker could possibly penetrate cyber defences.

A QUANTUM FUTURE

Mark Johnson, vice president of Quantum Technologies and Systems Products at D-Wave, tells us what makes the Advantage so groundbreaking and why we won't be throwing away the traditional computer just yet.

What's the difference between Advantage and a traditional computer?

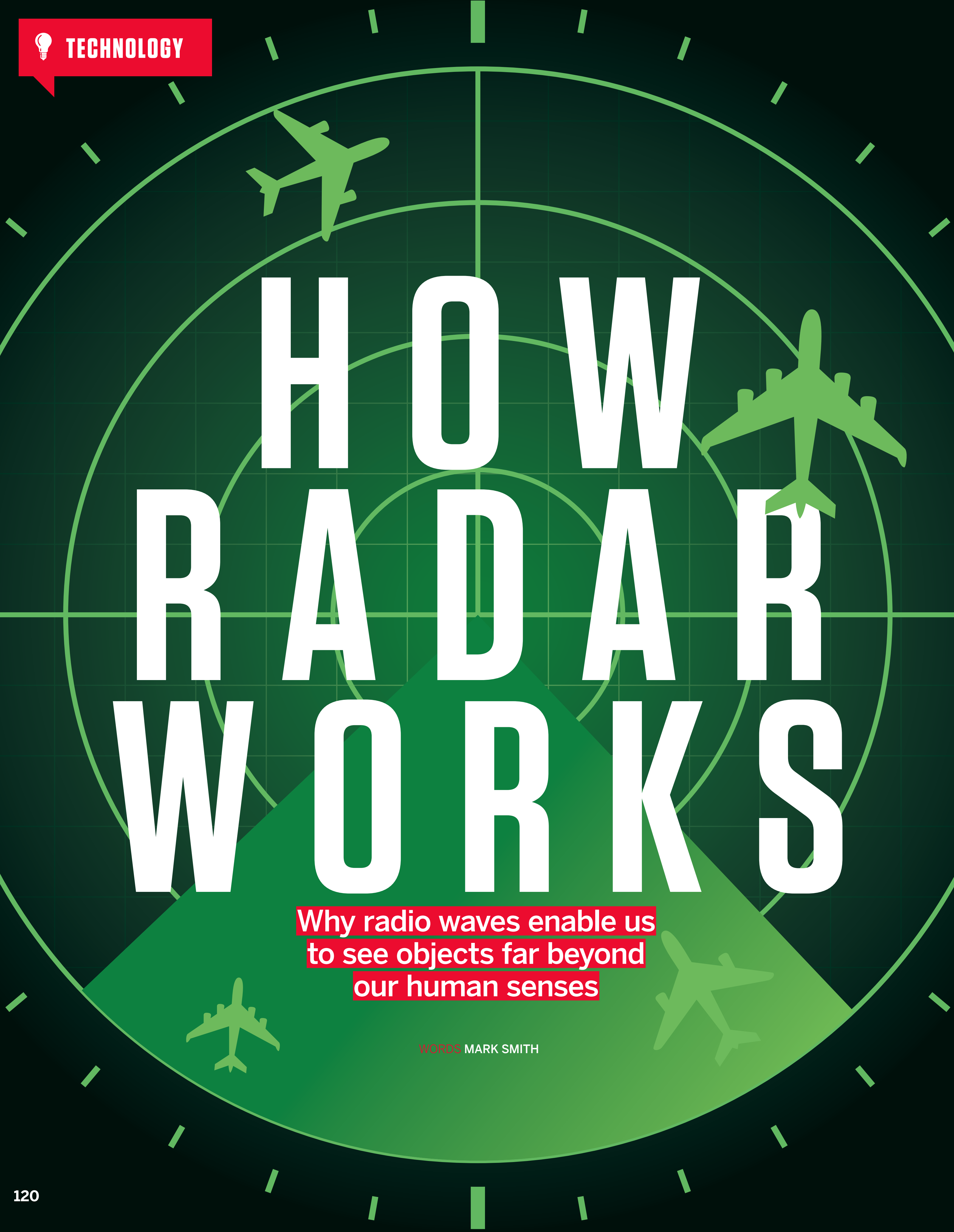
Advantage has the ability to harness quantum mechanics to solve problems. Advantage has upwards of 5,000 qubits, making it an incredibly powerful system. It only takes about 272 qubits to label every atom in the known universe with its own integer. Finding the solution to a 272-qubit problem is like finding the right atom out of all the atoms in the universe. It's hard to really comprehend how hard a 5,000-qubit problem could be, yet there are problems humans face that need this and more.

What was the toughest part of developing Advantage?

We launched our Advantage system in September 2020, which was a tremendous breakthrough for our company. Developing and building the system took more than 100,000 hours over a period of five years. The new architecture allows qubits to go from six-way connectivity in the D-Wave 2000Q to 15-way connectivity, allowing users to solve much larger and far more complex enterprise-level problems.

What kind of use do you envisage for Advantage now and in the future?

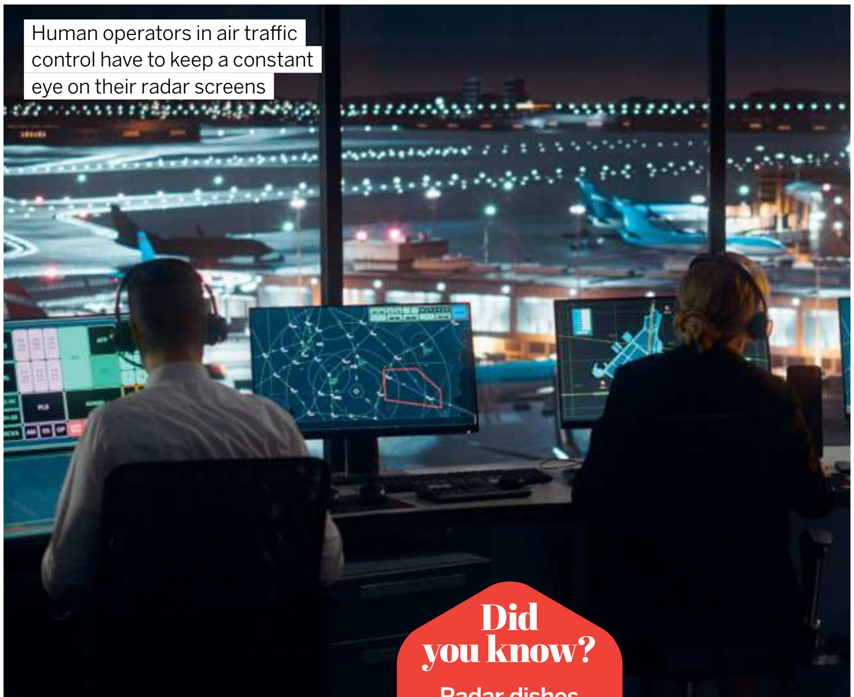
We continue to envision Advantage and other forthcoming systems from D-Wave as ideal quantum computers for business use. Our customers have seen success in financial services, pharmaceuticals and drug development, manufacturing, logistics and others. One of our customers, Menten AI, is creating the next generation of protein-based therapies using quantum computing. In the short term and in the longer term, we will all begin to benefit from quantum computing. From getting better personalised offers from companies who want to sell us things to finding new proteins to discover new therapeutics, quantum computing will impact us all.



HOW RADAR WORKS

Why radio waves enable us to see objects far beyond our human senses

WORDS MARK SMITH


Human operators in air traffic control have to keep a constant eye on their radar screens


Modern military radar systems are some of the most sophisticated in the world

Did you know?
Radar dishes spin so that they can scan a wider area

Anxiously standing around a giant map in the control room, Royal Air Force (RAF) personnel would spend each day watching and waiting, until eventually the call would come: "Raid incoming. Scramble all squadrons." History is filled with turning points, and World War II was no different, with many chance events, missed opportunities and strategic blunders contributing to Hitler's plans for world domination being dashed. But among all the technical breakthroughs that helped Britain and the Allies emerge victorious, it's impossible to overstate just how important radar was in the Battle of Britain, the air war fought over UK skies in 1940. Hitler had planned to invade, but needed to gain air superiority. He sent wave after wave of his numerically superior Luftwaffe against the UK, with bombers targeting London and RAF air fields. Outgunned and outnumbered, the RAF would need a miracle to win. And that miracle was called radar.

Radar – which stands for radio detection and ranging – harnessed radio waves to detect incoming German aircraft. From radar towers dotted around the south and east of the country, the system would emit radio waves that would keep travelling until they bounced off something, like an incoming plane, and would return to be picked up by the radar receiver. By calculating how long it had taken the waves to return, skilled operators could figure out the altitude, range and bearing of incoming enemy planes. This gave the RAF enough time to scramble its own planes to meet the incoming threat, helping Britain win the battle and landing a killer blow to the invasion plans of the Third Reich.

Although this enormously successful trial by fire made radar a household name, the technology behind it started life much earlier and centred around the study of electromagnetic (EM) waves. EM radiation is a form of energy that's everywhere and can take on lots of different forms, such as radio waves, microwaves, X-rays, ultraviolet – which we receive as sunlight – and gamma rays. EM waves also form the basis of how mobile phones and wireless computer networks function.

In 1885, Scottish physicist James Clerk Maxwell came up with the idea that perhaps radio waves could be reflected by metal objects,

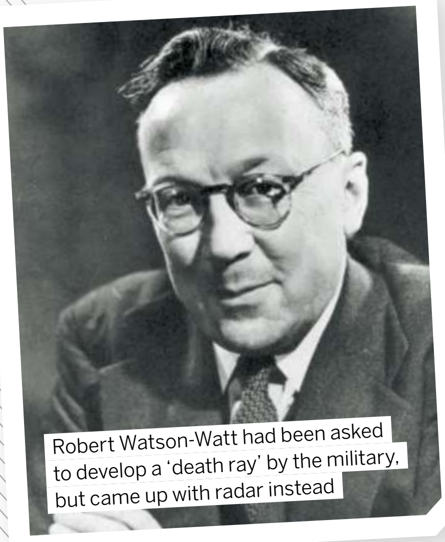
"It's impossible to overstate just how important radar was in the Battle of Britain"

just like light waves could. A few years later, German physicist Heinrich Hertz set out to prove it. In an experiment he conducted in 1888, he discovered that they were indeed reflected back, and in 1904 a patent was issued to a German engineer called Christian Hülsmeyer for what was termed 'an obstacle detector and ship navigation device'. It didn't have a very catchy name, but a type of early radar system had been created. Despite that, it wasn't until the 1930s that there was a need for the technology, mainly due to the invention of long-range military bombers that prompted countries to invest in a system that could detect their approach and provide early warning.

DOPPLER RADAR

The biggest advance in post-war radar technology was Doppler radar. With the need to defend against bombers gone, the new motivation to refine the technology was using it to track the weather. While ordinary radar can figure out range and location, Doppler can also tell us information about an object's speed. It works on the principle of the Doppler effect, the idea that waves produced by an object will be squeezed closer together if it's moving towards you, or spread out if moving away. This is invaluable for tracking weather systems. They can gather a huge amount of information, so modern Doppler radar depends on increasing processing power. Doppler radar is also what you would find in a police speed gun.


Police speed guns use Doppler radar to track how fast vehicles are moving



Robert Watson-Watt had been asked to develop a 'death ray' by the military, but came up with radar instead

SEA-GOING POLARIMETRIC

How the world's most advanced shipborne radar works

1 4.3-METRE ANTENNA
The reflector antenna dish is sufficiently large enough to receive powerful radar pulse reflections.

2 FIBREGLASS RADOME
A protective fibreglass radome houses the antenna and pedestal, as well as various electrical components.

3 INU ANTENNA
The inertial navigation unit antenna senses the pitch and roll of the radar platform while at sea.

4 RADOME PLATFORM
This is where the crew stand to carry out maintenance and repairs.

5 RADAR SHELTER
This uses a modified shipping container that can be easily moved by dockside equipment like forklift trucks.

6 PROTECTIVE PAINT
The outside is covered with hydrophobic paint to reduce formation of water films that can distort readings.

7 TOUGH DESIGN
SEA-POL was designed to be rugged so it could operate even in the harshest ocean environments.

8 ANTENNA POSITIONER
This allows positioning in azimuth and elevation so the direction of radar pulses can be controlled.

CHAIN HOME

In the early days of World War II, a 'chain' of radar stations had been constructed along the south and east coast of the UK. Known as Chain Home stations, they could detect incoming aircraft at a range of 80 miles. They were gigantic, at over 100 metres high. With the invention of the cavity magnetron in 1940, much smaller but more powerful radar units harnessing microwaves could be built, which meant they could be installed on ships and planes.

In 1939 Chain Home had 18 radars, growing to 53 before the war ended

KEY DATES IN THE DEVELOPMENT OF RADAR

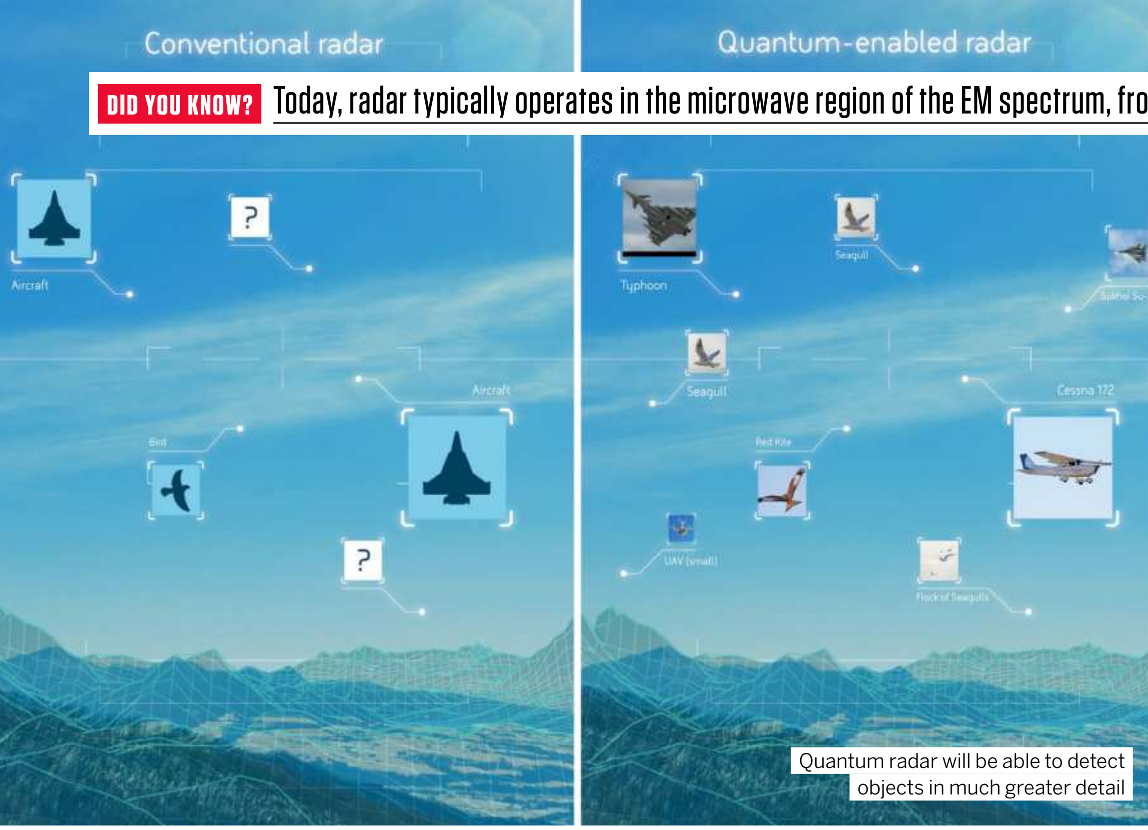
1888
Heinrich Hertz discovered that electromagnetic waves could be reflected from various objects and focused into beams.

1904
German engineer Christian Hülsmeyer was granted a patent for using electromagnetic waves in an obstacle detector and navigation device for ships.

1922
Radio pioneer Guglielmo Marconi suggested short waves could be used for radio detection.

1930
A study by Lawrence Hyland from the US Naval Research Laboratory indicated it was practical to detect ships and aircraft using continuous waves.

1934
The US Army Signal Corps used continuous waves to detect targets at very short ranges, suggesting the possibility of using pulsed energy to observe targets at longer ranges.



DID YOU KNOW? Today, radar typically operates in the microwave region of the EM spectrum, from 400 megahertz to 40 gigahertz

Quantum radar will be able to detect objects in much greater detail

All of the major world powers at the time were researching radar, but it was the US and UK that were able to refine the technology. Scottish physicist Sir Robert Watson-Watt, known as 'the father of radar', built upon the science that had come before and created the workable system that formed the basis of what we have today.

Radar continues to be in widespread use today, but the technology has advanced to harness microwaves, which are at the higher frequency end of the radio spectrum and provide more accurate readings. A typical radar system has four main components: a transmitter, which generates the radio pulse; an antenna, which sends the pulse out into the ether and receives it when it's reflected back; a switch, which tells the antenna when to transmit or receive the pulses, and a receiver, which detects and turns the pulses that come back into a visual format that can be read by an operator.

The process of directing radio waves towards objects is called illumination, although radio waves are invisible to the human eye, as well as optical cameras. They are sent out at around 300,000,000 metres per second – the speed of light. Some of the reflected radio waves, or echoes, are directed back towards the radar where they are received and amplified, with the data being interpreted by skilled operators with the help of computers. Once returned, they provide information such as range and bearing.

Did you know?

Radar is considered an active remote sensing system

Radio waves are cheap to generate; can pass through snow, mist and fog and are safe, unlike gamma rays and X-rays. Radar can be used to detect ships, planes and satellites. Closer to home, radar speed guns are used by the police to calculate how fast cars are going, with any that are going too fast in line for a speeding ticket. Meteorologists also use radar to map and track weather systems around the world.

Germany lost more than 1,700 planes in the Battle of Britain, nearly twice as many as the RAF

1935
Robert Watson-Watt proposed a system almost identical to the US Army's idea and produced a successful prototype.

1937
Colonel William Blair, director of the US Army Signal Corps laboratories at Fort Monmouth, patented the first US Army radar.

1939
The invention of the cavity magnetron allowed radars to become smaller and more accurate by harnessing microwaves.

1950s
The application of the Doppler principle to radar began, leading to the creation of modern Doppler radar systems.

1990s
The continued development of computers and processing technology allowed for radar signals to be interpreted with better accuracy.

THE QUANTUM GENERATION

Henry White, sensing technologist at BAE Systems, talks about how quantum radar takes detection to a whole new level

Can you explain how this new technology works?
Every radar uses a clock to measure how long waves take to bounce off an object and come back to the antenna. The time delay tells you how far away an object is, so you can also tell how quickly it's moving while you track it. If you can make the clock more accurate, then you can begin to actually detect the shape of an object and work out exactly what it is. We're currently researching how to insert a quantum clock into radar, which is about a thousand times more accurate than the clocks we use now. These clocks aren't ready yet, but we're doing the groundwork now to use them when they are.

What can quantum radar do that traditional radar can't?
It'll be able to detect more objects, in more detail, at greater range. While now you might only be able to detect a bird, with quantum radar we think you'll be able to tell the species of bird and how many are in the flock. It should be able to tell you the make and model of a drone, which is really useful data if you're running an airport, for instance.

What do you envisage it being used for?
For the military, you should be able to identify friend or foe at much greater distances, as well as the type of physical weapons they're carrying. Being able to do this at greater range will affect how fast or stealthy you might want to design a plane. You could see civilian users, such as air traffic control, using this radar to monitor drones, which can be a real threat to them. Ultimately, it's about being able to see more clearly and give people an information advantage over potential enemies.

INSIDE A VACUUM CLEANER

How do these household cleaning machines suck up dirt and dust?

WORDS **AILSA HARVEY**

Whether your vacuum cleaner plugs into the wall, is a handheld device or performs its job automatically as a robot, the science behind these appliances is largely the same. Vacuum cleaners efficiently collect small particles through suction, which involves manipulating the movement of air particles by altering the pressure near them. When the pressure of the air inside a vacuum cleaner is lower than the air outside, particles rush towards the lower pressure.

This process falls under a scientific idea called Bernoulli's principle, which dictates how vacuum cleaners control air flow. To create a lower air pressure inside the vacuum cleaner, air particles need to be moving faster. The speed of particles inside the vacuum is increased by an internal fan. As the difference in air pressure increases, external air rushes with speed towards the fan to balance this, carrying light particles of dust and dirt from nearby surfaces through the vacuum's small opening.

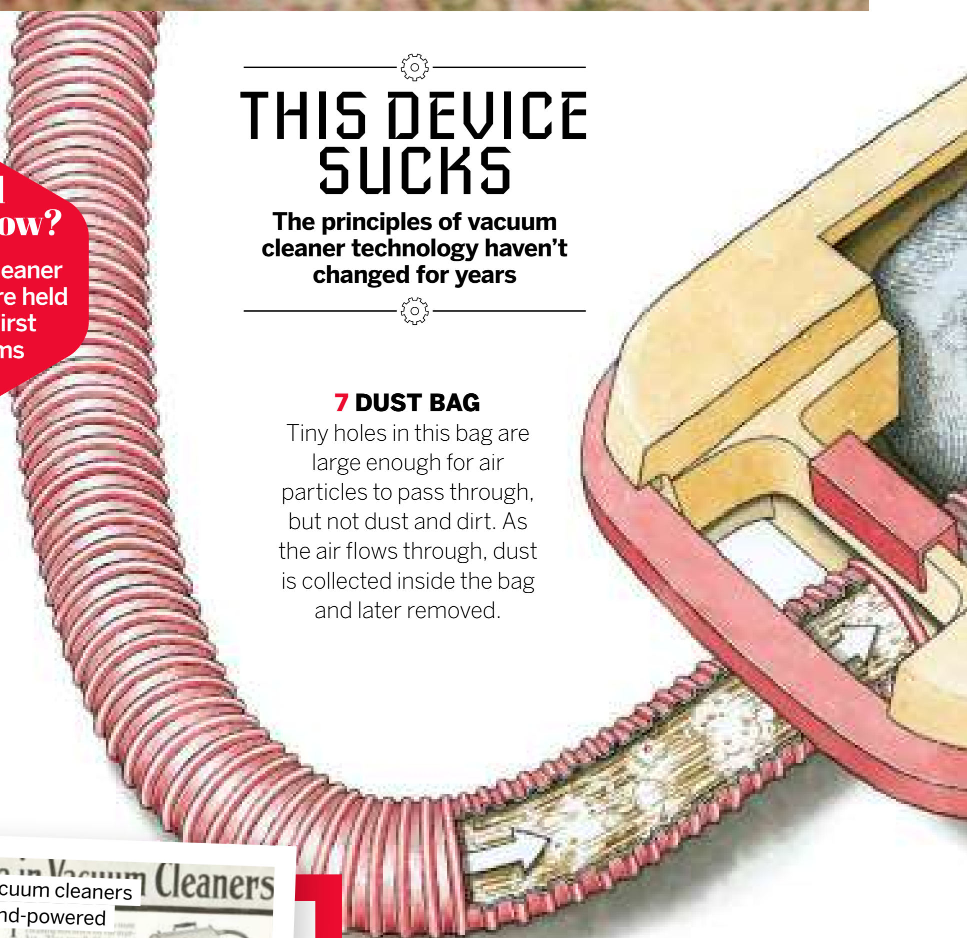
Carpets full of crumbs are easy to clean

Did you know?

Vacuum cleaner parties were held for the first vacuums

THIS DEVICE SUCKS

The principles of vacuum cleaner technology haven't changed for years



7 DUST BAG

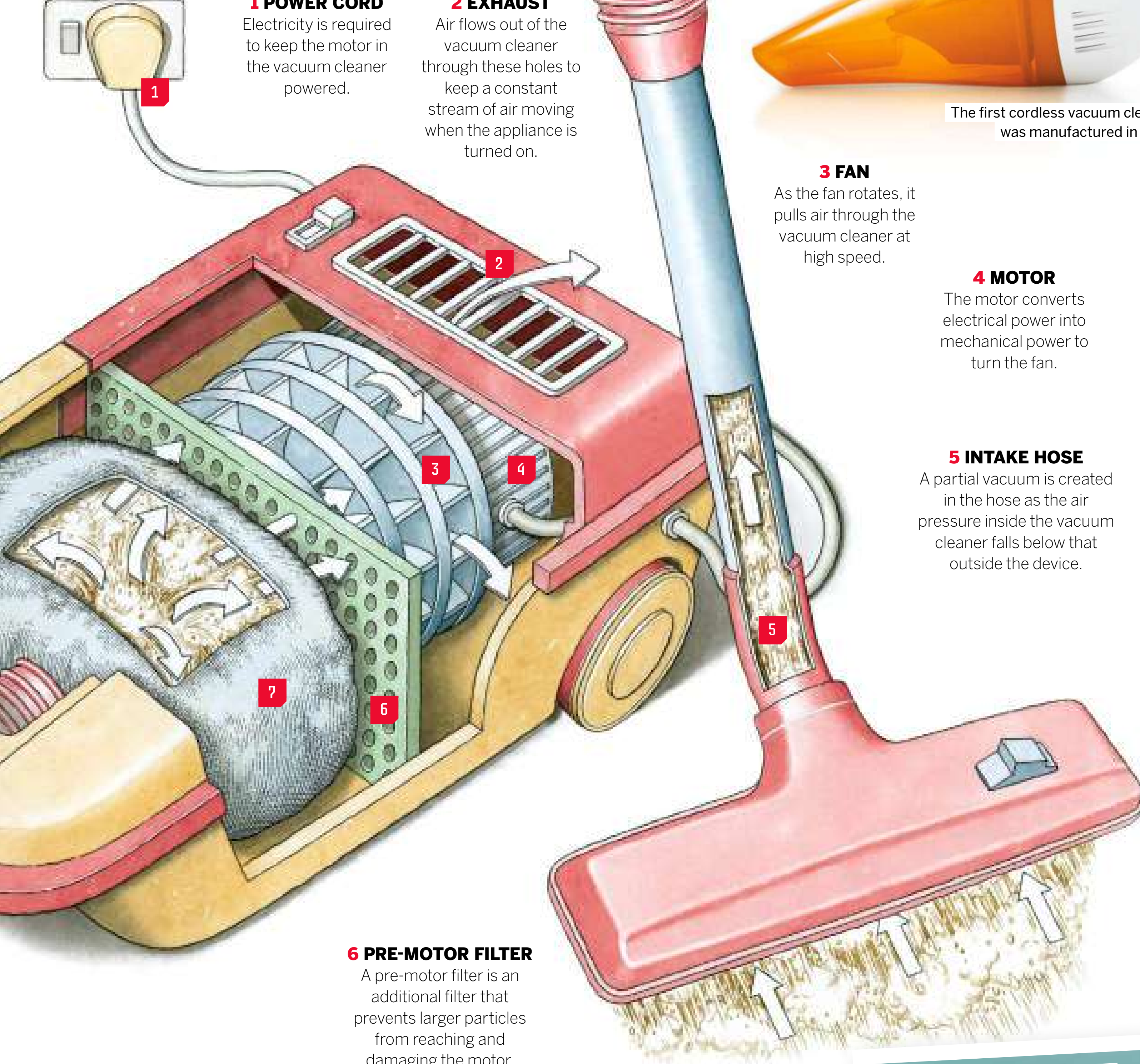
Tiny holes in this bag are large enough for air particles to pass through, but not dust and dirt. As the air flows through, dust is collected inside the bag and later removed.

HOUSEHOLD FIRST

In 1901, British engineer Hubert Cecil Booth invented a machine that could suck up dirt in homes. This early version wasn't as accessible as the one you likely have stored in a cupboard at home. The first vacuum cleaners were large horse-drawn units that required around six people to operate. When the vacuum cleaner reached the house where its wealthy occupants had paid to hire it, its hoses were fed through the windows and used to remove any dust. It wasn't until 1908 that the smaller, handheld appliances we know today were invented by William Henry Hoover.

Early vacuum cleaners were hand-powered

Dirty filters reduce the ability of air to flow through vacuum cleaners



1 POWER CORD
Electricity is required to keep the motor in the vacuum cleaner powered.

2 EXHAUST
Air flows out of the vacuum cleaner through these holes to keep a constant stream of air moving when the appliance is turned on.

The first cordless vacuum cleaner was manufactured in 1979

3 FAN
As the fan rotates, it pulls air through the vacuum cleaner at high speed.

4 MOTOR
The motor converts electrical power into mechanical power to turn the fan.

5 INTAKE HOSE
A partial vacuum is created in the hose as the air pressure inside the vacuum cleaner falls below that outside the device.

6 PRE-MOTOR FILTER
A pre-motor filter is an additional filter that prevents larger particles from reaching and damaging the motor.

ROBOT UPRISING

Wireless robots can navigate rooms automatically, with no human input until they need to be emptied. With a series of rotating brushes and infrared lasers, these circular devices sense the boundaries of the room and sweep any dirt into their dust compartment. Robots can carry out multiple vacuuming sessions before needing to be emptied, and are charged at a docking station. Some people preprogram these vacuums so that they clean up on schedule, while others start the process manually. Most robot vacuum cleaners come with a remote control, allowing the user to direct it to specific areas or return the vacuum to its dock before it has carried out its full routine.

Robotic vacuum cleaners scan the floor and navigate it methodically

Protective eyewear needs to be worn when using a plasma cutter because of the extremely bright light emitted

HOW PLASMA CUTTERS WORK

The science behind these efficient metal-slicing tools

WORDS AILSA HARVEY

Heat has the ability to change the state of matter. It can melt a solid into a liquid and evaporate a liquid to become a gas. The fourth state of matter is plasma. When matter is heated to extreme temperatures, gases can become ionised. This means a gas' atoms lose their electrons, giving them a positive charge.

Plasma cutters are tools that use this hot plasma to cut through metal. As plasma has high energy, it travels in fast streams out of the plasma cutter. As it does, it carries electrical energy created inside the machine and transfers it onto metal. The plasma produced can reach temperatures far hotter than the surface of the Sun, at over 20,000 degrees Celsius.

When the high-energy plasma comes into contact with the metal, it reverts to its original gaseous state. In doing this it releases the extreme heat it was carrying. This heat melts the metal to cause a break in the targeted area. Plasma cutters are often handheld tools, giving the user control of where the cuts are made.

At this scrap metal recycling facility, metal is being cut into smaller, flat pieces

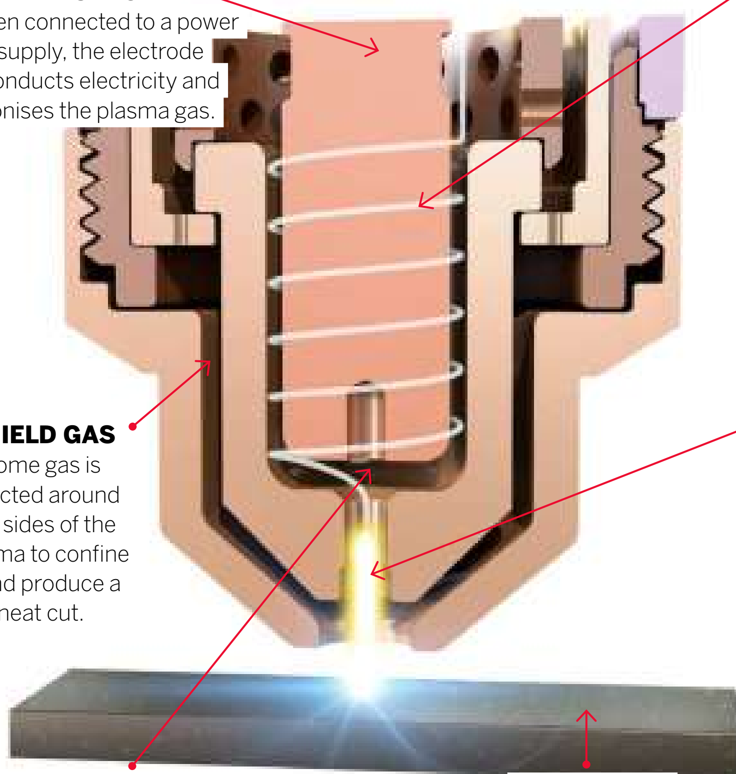
WHO USES THEM?

There are many industries in which cutting metal is required. These range from locksmiths, who help to cut open locked safes and vaults, to workers in metal recycling plants, who break up metal into small, manageable pieces. Any repair work on metal would also benefit, such as the repair of cars and farm equipment. Aside from these industrial applications, plasma cutters are popular for creative uses. They are commonly used by metal artists to create intricate metal structures. The cutting precision of these tools increases the level of detail that can be produced with metal.

This detailed metal sculpture is being cut using a plasma cutter

CREATING A CUT

How these tools use gas and electricity to shape metal



ELECTRODE
When connected to a power supply, the electrode conducts electricity and ionises the plasma gas.

PLASMA GAS
Oxygen, argon or nitrogen flows around an electrode towards the nozzle.

PLASMA STREAM
As the ionised gas forms around the nozzle, it creates a path between the electrode and the work piece for the electric current.

SHIELD GAS
Some gas is directed around the sides of the plasma to confine it and produce a neat cut.

CREATING A SPARK
A spark first forms between the electrode and the nozzle, causing some of the gas to become ionised.

WORK PIECE
The conductive metal is melted by the electric energy, while the ionised gas pushes the molten metal away for a clear cut.

HOW DO ELECTRIC KETTLES WORK?

These are the components inside a kettle responsible for bringing it to a boil

WORDS AILSA HARVEY

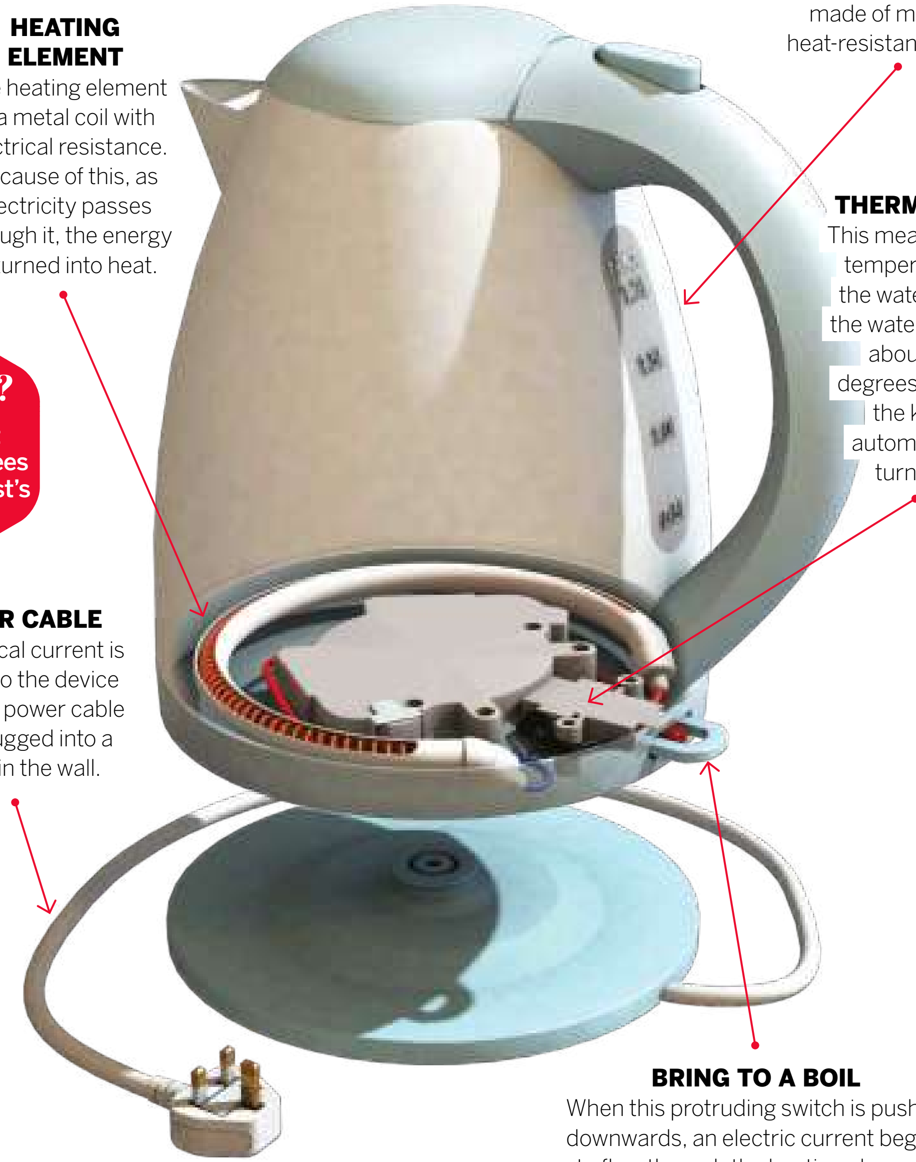
Did you know?
Water boils at around 68 degrees Celsius at Everest's summit

People have been boiling water for thousands of years for purposes such as killing bacteria, cooking or brewing a drink. Whereas some of our early ancestors would have needed to build an open fire to get their water bubbling, today we can boil water in a couple of minutes simply by using a kettle. Electric kettles convert electrical energy into heat energy, and this is transferred to the water much more efficiently than by an open fire. While an open fire allows heat to escape into the surrounding air, kettles include a lid to trap the heat inside and insulation around the element that heats the water.

You'll know when the water in a kettle is nearly ready to use because the noise of the water approaching boiling point will increase significantly. This sound is caused by the bubbles being created in boiling water. When boiling, water gains energy from the heat produced. The water molecules begin to move more quickly until they have too much energy to remain as a liquid. When this happens, the water becomes a gas, in the form of water vapour, and floats to the surface. This displacement of water, along with the popping of bubbles as they reach the surface, provides the signature sound of a boiling kettle.

INSIDE THE APPLIANCE

Electric kettles use a by-product of electrical resistance to heat the water inside



BOILING AT ALTITUDE

Because the boiling point of water decreases with lower air pressure, when used at high altitudes a standard kettle will never trigger the thermostat to automatically turn off. Water boils at 100 degrees Celsius at sea level; at 150 metres above sea level, its boiling point is lowered by about 0.5 degrees Celsius, continuing to reduce as altitude increases. If you want to make a cup of tea when high in the mountains, a variable temperature kettle is a good solution. This enables the user to alter the temperature setting depending on their elevation, allowing the kettle to automatically trip when the water boils.


Water boils quicker at higher elevations due to the lower atmospheric pressure

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Sound barrier smashers

SOUND BARRIER SMASHERS

Ever since humanity took to the skies, we've pushed the limits of speed, accelerating past sound to hypersonic speeds and beyond

WORDS **ROBERT LEA**

As the field of aviation grew and planes became faster around the mid-20th century, pilots began to experience strange phenomena when approaching speeds in excess of 700 miles per hour. Almost like hitting a physical barrier, further acceleration for these pilots and their aircraft was prevented by violent effects, sudden changes in temperature and pressure – almost like flying into a wall. Corresponding with the speed at which sound travels, this 'wall' would come to be known as the sound barrier. We now know this isn't an actual physical barrier, but is a sudden increase in aerodynamic drag that occurs as a vehicle approaches the speed of sound, at speeds that are described as 'supersonic'.

Sound propagates through air as a wave at around 761 miles per hour at sea level – a velocity also known as Mach 1, part of a measurement system for speed that takes its name from Ernest Mach, an important figure in the science of shock waves. Because sound waves use air as a medium, the density of air has a significant effect on the speed sound travels. Where the atmosphere is thinner at greater altitudes, sound travels slower. That means that pilots hit the sound barrier at slower speeds. At an altitude of 3.8 miles the sound barrier arrives at 707 miles per hour, while at 11.4 miles it drops to 660 miles per hour. Certain other conditions like temperature also alter the speed at which sound travels, and thus the sound barrier.

The forces experienced by an aircraft depend strongly on the speed it travels. At

A shock wave and air molecules form a cloud around the midsection of a F/A-18E/F Super Hornet as it approaches the speed of sound

speeds slower than sound – subsonic speeds of up to Mach 0.8 or 614 miles per hour – the air in front of an aircraft moves before the vehicle reaches it. This is because the sound waves – or more precisely pressure waves – created by the plane outrace it and spread out ahead of it. This continues through so-called transonic speeds of between Mach 0.8 and Mach 1, but the situation changes radically at supersonic speeds above Mach 1. The pressure waves no longer race ahead of the jet, shifting air from its path. This results in shock waves building around the aircraft. This also leads to a pressure cone building mostly behind the jet, triggering a famous effect of breaking the sound barrier: the sonic boom.

Sonic booms hit the ground between 2 and 60 seconds after a supersonic flyover, with the area exposed equivalent to roughly one mile for every 0.2 miles of altitude. That means a jet breaking the sound barrier at 5.6 miles causes a sonic boom spread across around 30 miles. The intensity of the sonic boom heard at ground level is determined by a number of factors. This includes how far above the ground the jet is and atmospheric conditions like pressure and temperature.

Did you know?

Swept wings on jets help them go supersonic

The shape of the jet is also a factor, with longer aircraft capable of causing a double sonic boom – one of which comes from its leading edge, and the other from the trailing edge. There are two types of sonic boom: N-shaped, which are caused by steady flight conditions and an N-shaped pressure wave, and U-shaped that result from jets engaged in flight manoeuvres at supersonic speeds. The strongest sonic boom ever recorded was 6.9 kilonewtons per metre squared and resulted from an McDonnell Douglas F-4 Phantom II flying above the speed of sound at an altitude of 30 metres.

Speeds above Mach 5 – five times the speed of sound or around 3,800 miles per hour – are described as being hypersonic. At hypersonic speeds, molecules of air around an aircraft start to break apart and ionise – they gain electric charge. While this doesn't happen at a set speed, the term 'hypersonic' is used to describe a point at which this phenomenon begins to affect the mechanics of flight. At high-hypersonic speeds above Mach 10 or around 7,700 miles per hour, the ionisation of molecules results in plasma – the same phase of matter that makes up the Sun – forming around the vehicle.

PRESSURE WAVES

As an aircraft approaches the speed of sound, conditions change radically, resulting in a pressure wave that ripples backwards through the air

STATIONARY | SUBSONIC | SPEED OF SOUND | SUPERSONIC

0 MILES PER HOUR
The aircraft is still and experiences the normal atmospheric air pressure at whatever altitude it's stationed in. The pressure field is even.

1 TO 767 MILES PER HOUR
Up to the speed of sound, air ahead of the plane moves before it's reached, allowing for smooth pressure waves travelling in all directions.

767 MILES PER HOUR
At the speed of sound, air is compressed and moves over the wings at supersonic speeds. A shock wave forms at the wings, causing a turbulent wake. Pressure, density, drag and temperature increase suddenly.

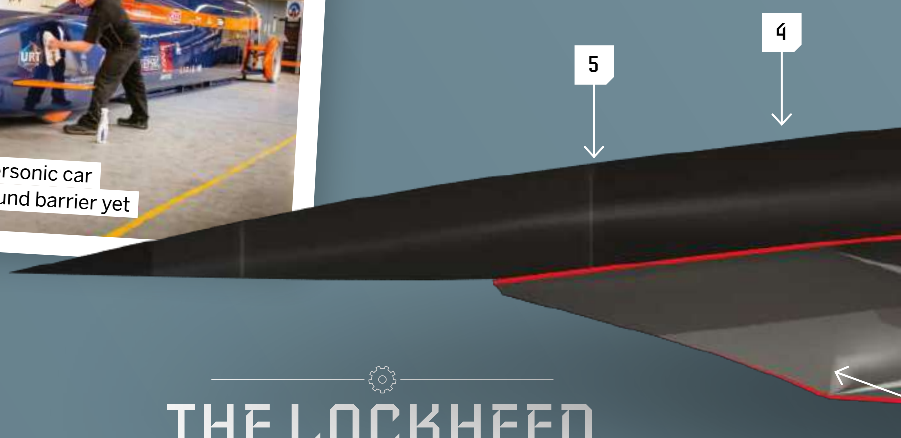
OVER 767 MILES PER HOUR
A further shock wave is formed at the wings' leading edges. The pressure field is confined to a widening cone mostly behind the plane.

BREAKING THE SOUND BARRIER

The Bloodhound supersonic car hasn't quite hit the sound barrier yet

Two main classes of vehicle are capable of breaking the sound barrier, with this feat usually achieved by aircraft and a small number of land vehicles that have in principle been capable of travelling faster than sound – but so far only one has officially done this. It was aircraft pilots that first discovered the existence of the sound barrier during World War II, when their planes began to experience the effects of air being compressed as they approached the speed of sound, giving rise to often severe adverse effects. This included airflow over the wings that made pulling out manoeuvres difficult and shock waves on wings causing 'flutter', costing the life of at least one pilot, Geoffrey de Havilland Jr.

This led to the concept of a physical barrier that restricted the acceleration of aircraft, spurring the quest to smash this barrier. Advances in aircraft design like tiled wings and engine performance led to the sound barrier being broken as a matter of routine in the 1950s, and later to an array of craft that could go supersonic, including one passenger jet: the Concorde. On 15 October 1997, the first vehicle officially achieved the same feat on land. The British-designed and built ThrustSSC, driven by Andy Green, achieved a speed of just over 763 miles per hour – Mach 1.016 – over a mile-long stretch of the Rock Desert of Nevada. The car was powered by two engines, the same as used in F-4 Phantom II jet fighters.



THE LOCKHEED MARTIN SR-72

The Lockheed Martin SR-72 is a hypersonic unmanned aerial vehicle (UAV) designed for reconnaissance that could fly by 2025

1 TURBINE POWER
Turbines similar to those used in modified fighters form part of the SR-72's advanced propulsion system. These take the jet to Mach 3.

2 DUAL SCRAMJET
The other key component of the jet is a dual-scramjet through which air passes at supersonic speeds. This kicks in to boost it right up to hypersonic speeds.

3 BREATHE IN… AND OUT
An air inlet allows air to pass through to the ramjet engine and the turbines. Air is then released from an outlet at the rear of the jet, with a single inlet and outlet reducing drag.

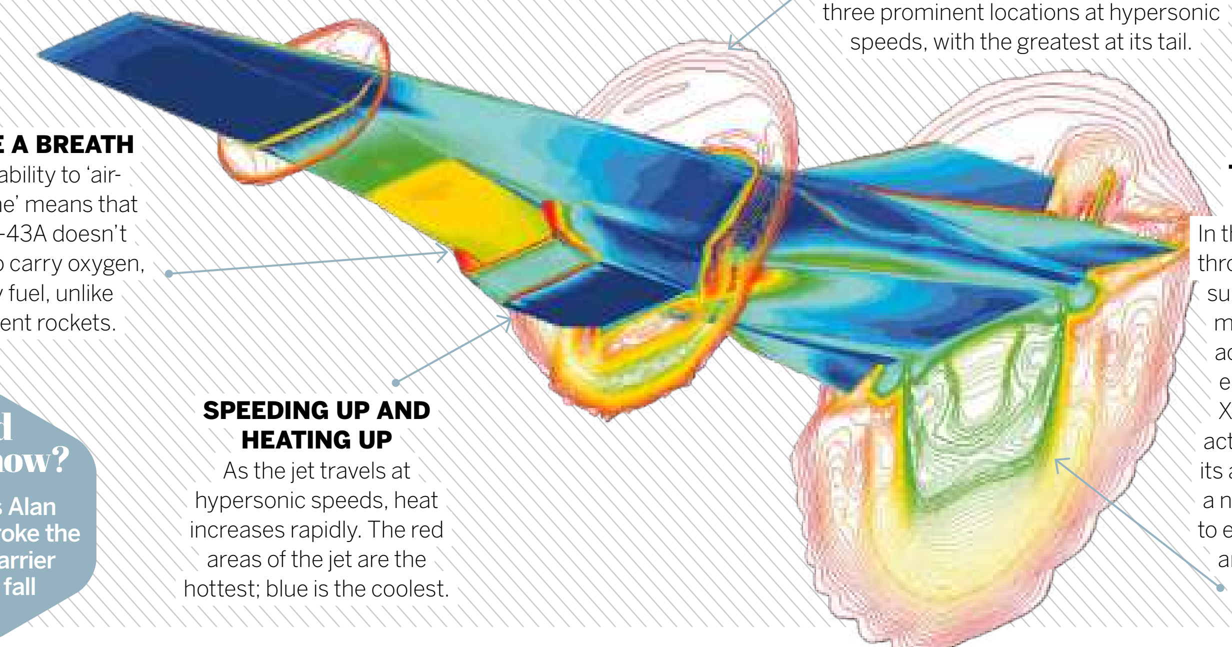
4 NO DRAG
The jet's design reduces drag and friction, which can heat the body of a hypersonic aircraft enough to melt it.

5 EMPTY COCKPIT
The prototype, which may or may not have already flown, will be unmanned, but a human could take direct control of a similar model in the future.

6 HYPERSONIC EXHAUST
This powerful engine and bodywork combination could push the unmanned SR-72 to reach speeds up to and potentially above Mach 5.

BEYOND MACH 5

This computational image shows air flowing over NASA's X-43A, supersonic combustion ramjet as it travels at Mach 7



UNDER PRESSURE
Pressure waves build around the jet in three prominent locations at hypersonic speeds, with the greatest at its tail.

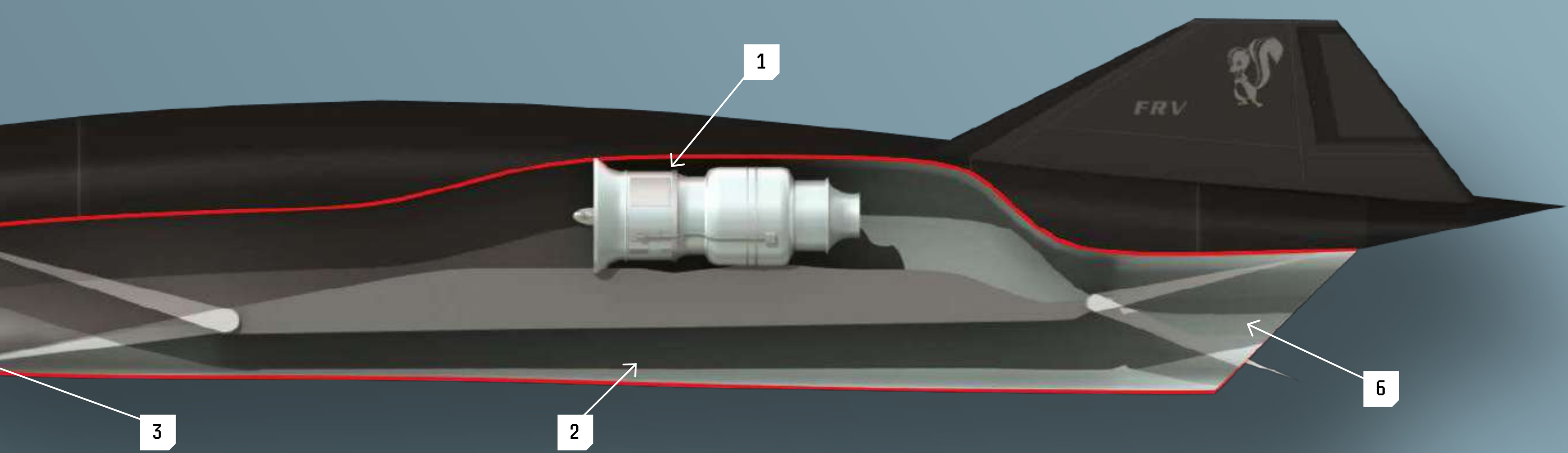
TAKE A BREATH
The ability to 'air-breathe' means that the X-43A doesn't need to carry oxygen, only fuel, unlike current rockets.

SPEEDING UP AND HEATING UP
As the jet travels at hypersonic speeds, heat increases rapidly. The red areas of the jet are the hottest; blue is the coolest.

THE ENGINE BODYWORK
In these jets, air flows through the engine at supersonic speeds, meaning the body acts as part of the engine. While the X-43A's forebody acts as an air intake, its aft section acts as a nozzle, allowing air to escape. One inflow and outflow of air reduces drag.

Did you know?
Google's Alan Eustace broke the sound barrier in free fall

DID YOU KNOW? In 1953, Jacqueline Cochran piloted a Canadair Sabre to become the first woman to break the sound barrier

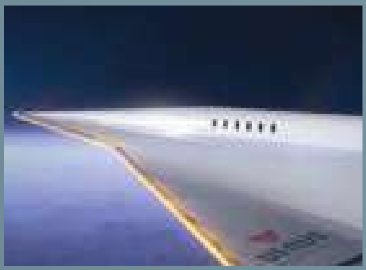


SPEEDING THROUGH THE SKIES

BOOM OVERTURE

TOP SPEED
1,300 miles per hour (Mach 1.7)

Designed by Boom Technology, the aim of the Overture is to bring supersonic jet travel back to the public. In this way, the craft is picking up where Concorde left off in 2003. Supersonic tests of Overture will be conducted in 2025, with the first commercial flight set for 2029.



VENUS AEROSPACE STARGAZER

TOP SPEED
6,905 miles per hour (Mach 9)

In June 2022, Venus Aerospace unveiled its design for a hypersonic space plane known as Stargazer. The craft is designed to launch from a conventional airport and soar to the edge of space, reaching speeds as great as Mach 9, and is also capable of one-hour global travel.

BOEING VALKYRIE

TOP SPEED
3,840 miles per hour (Mach 5)

The Valkyrie is a proposed military vehicle that features a unique flattened design that allows it to reach speeds in excess of Mach 5. The key to the jet's hypersonic velocity could be how its unique design with 2D air inlets handles drag as it hits supersonic speeds.

MAKING HISTORY

On 14 October 1947, American test pilot Charles "Chuck" E. Yeager became the fastest man alive when he broke the sound barrier for the first time. Yeager made history in a Bell X-1 rocket plane, which he nicknamed 'Glamorous Glennis' after his first wife. At an altitude of eight miles, the test pilot relit a third chamber of the plane's engine, causing it to accelerate to Mach 0.98. Yeager climbed another 304 metres, increasing speed and becoming the first man to officially travel faster than sound.

The public was made aware of the feat in 1948 and Yeager was awarded the Collier trophy – a prestigious aviation award – with the awarding body calling his 14 October flight the most important in aviation history since the Wright brothers' in 1903.

Chuck Yeager stands by the Bell X-1 supersonic rocket plane that took him beyond the speed of sound in 1947

5 UNLIKELY SOUND BARRIER SMASHERS

1 WHIP IT
In 1958 it was discovered that the loud crack created by snapping a bullwhip is actually a tiny sonic boom created by the tip of the whip breaking the sound barrier.

2 NO TROUBLE FOR TOWELS
An infamous high school locker room gag, whipping a towel at an unsuspecting teammate and causing a cracking sound is the result of the tip of the towel travelling faster than sound.

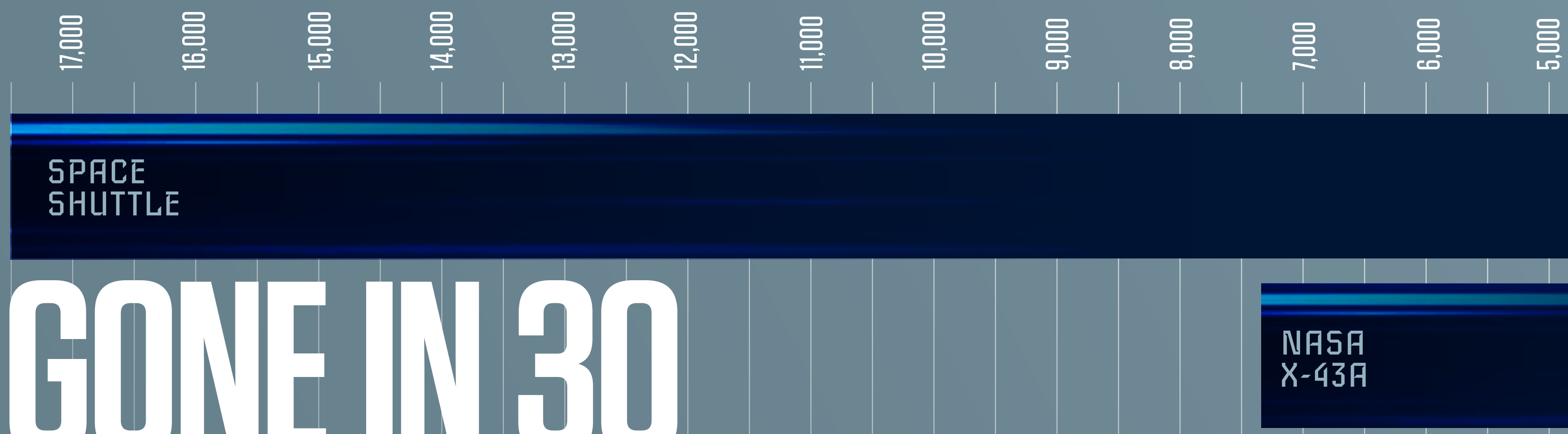
3 FLAG THIS ONE
A flag on a flagpole buffeted in a strong wind can cause a sonic boom when its leading edge goes supersonic.

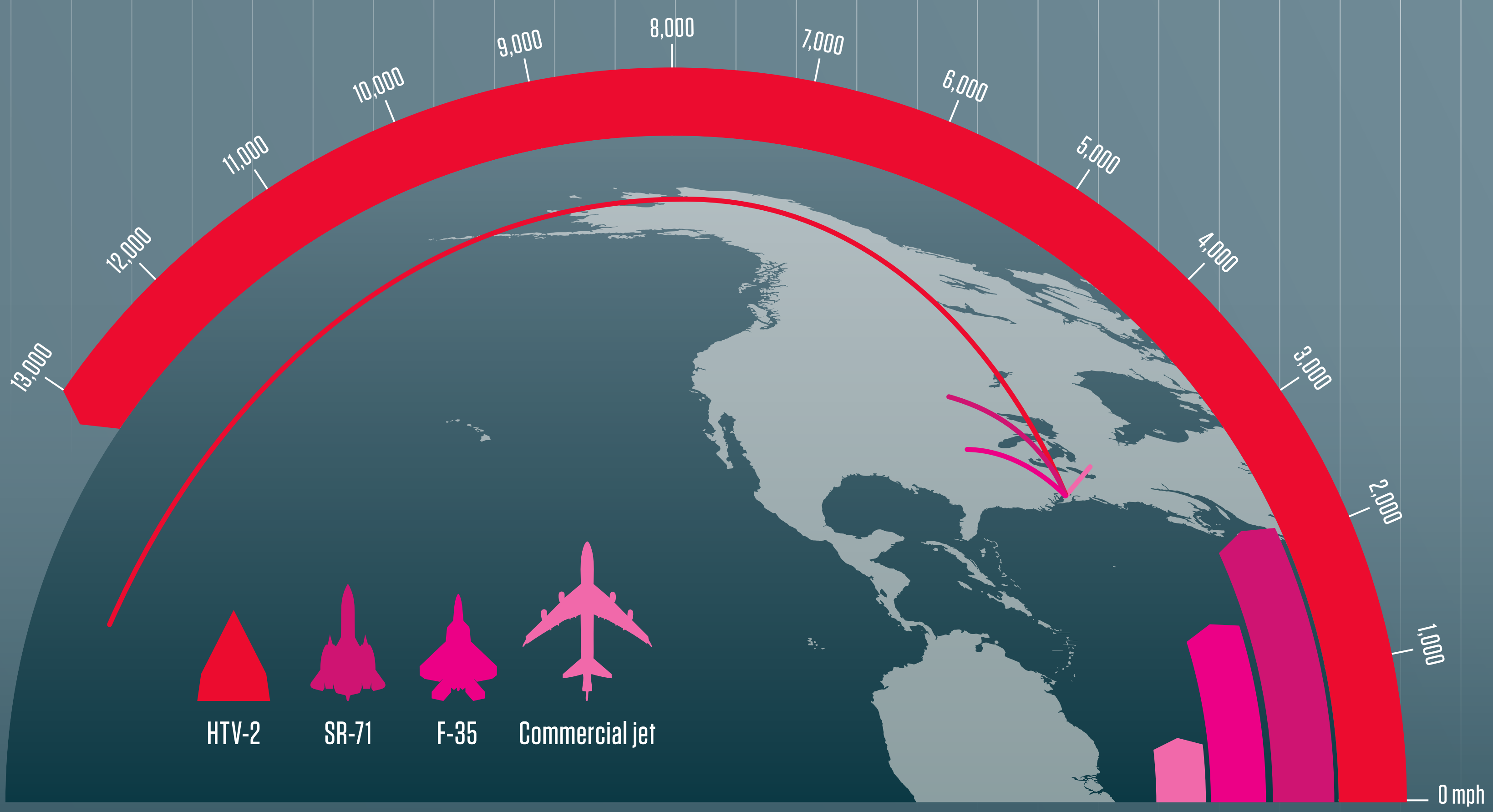
4 A BRUTAL GAME OF PING PONG
In 2018 Mark French and a team from Purdue University created a ping pong bazooka capable of launching these light, hollow plastic balls to speeds exceeding Mach 1.5.

5 FELIX IN FREE FALL
In 2012, Felix Baumgartner leapt from a balloon 24 miles above New Mexico. Not only did he break the then-world-record for a free fall, but travelling at 843.6 miles per hour, or Mach 1.25, he also broke the sound barrier.

GONE IN 30 MINUTES

Ten of the fastest vehicles ever devised race as far as they can in 30 minutes





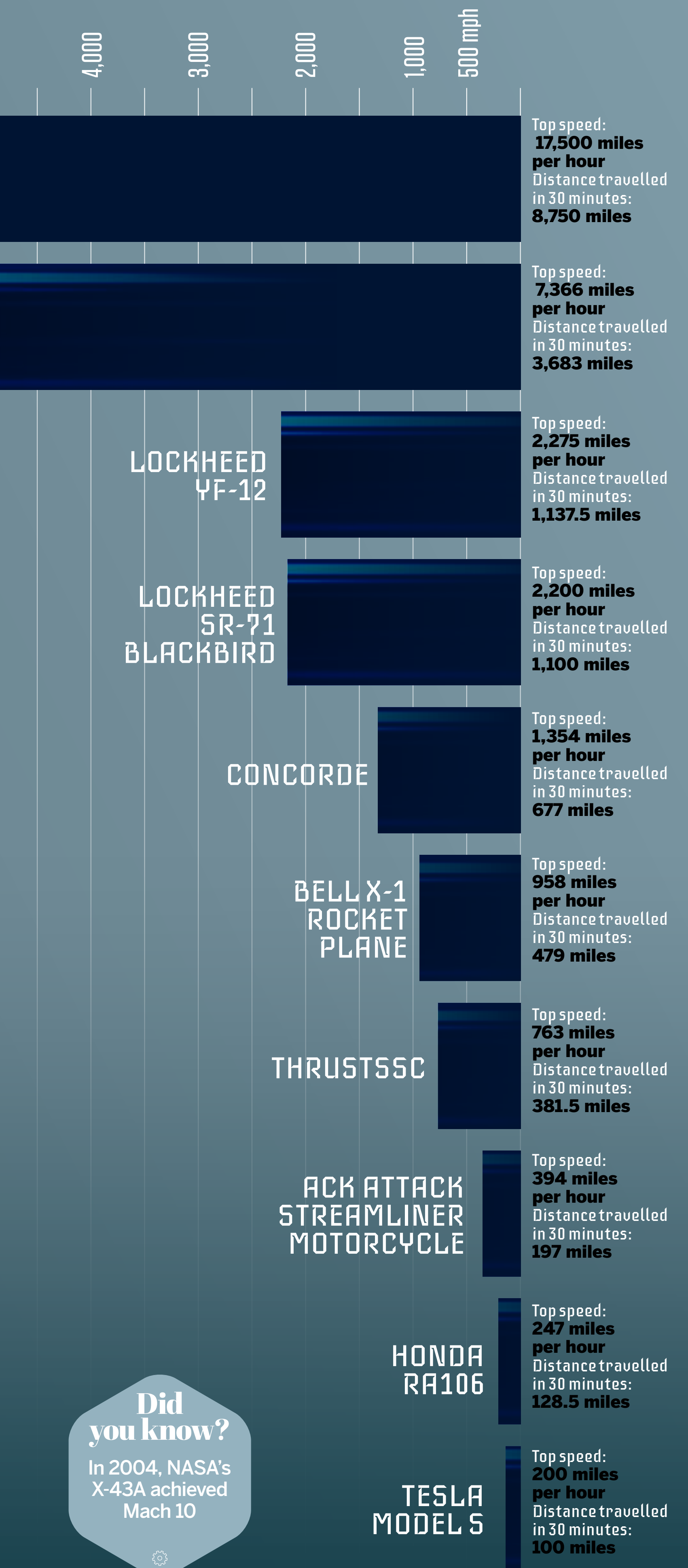

Concorde carried the general public to speeds beyond sound


The ThrustSSC still holds the land speed record


Baumgartner preparing for his barrier-breaking free fall


The crack of a whip is a tiny break of the sound barrier

DID YOU KNOW? An aircraft experiencing a tailwind can have a ground speed faster than sound without breaking the sound barrier



The Space Shuttle is one of the fastest human-made vehicles

The SR-71 Blackbird can pass Mach 3

The RA106 raced in the 2006 Formula 1 season

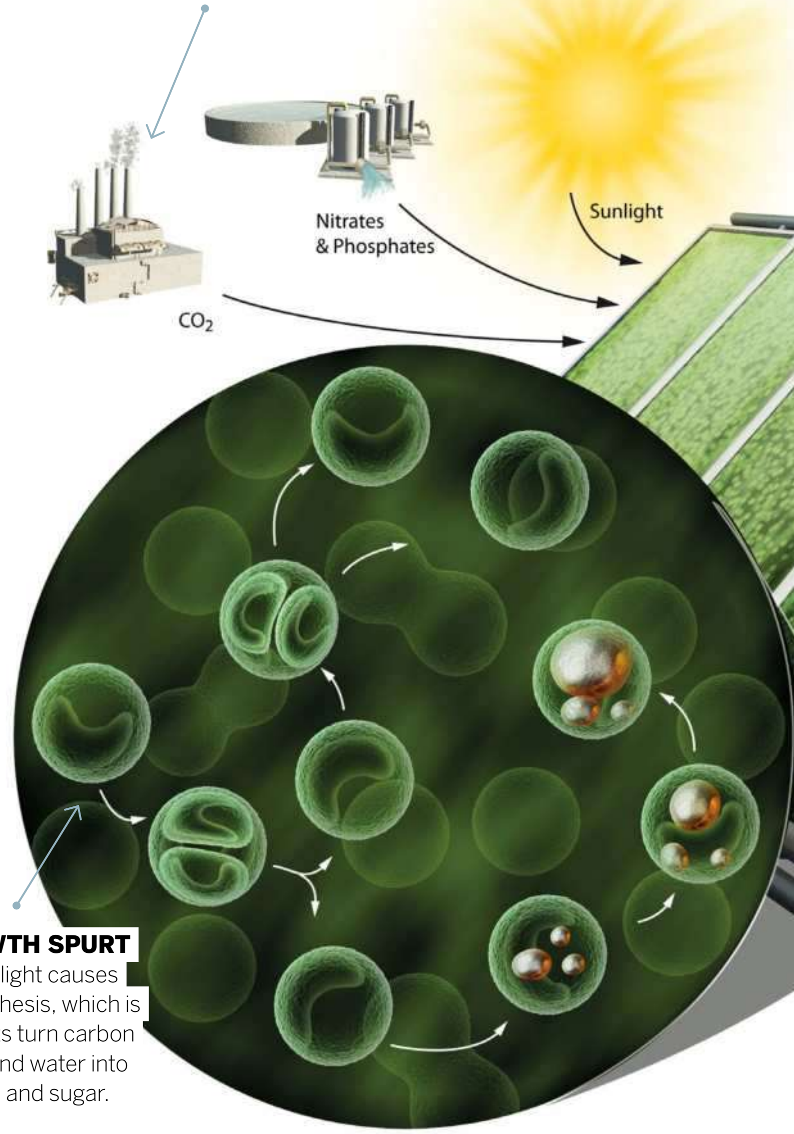
The Tesla Model S is speedy for an all-electric vehicle

Did you know?

In 2004, NASA's X-43A achieved Mach 10

85 per cent of liquid biofuel that's produced globally uses ethanol

3 CLEANUP
Algae grows quickly, and it efficiently removes harmful carbon dioxide, nitrates and phosphates from the air.



2 GROWTH SPURT
The sunlight causes photosynthesis, which is how plants turn carbon dioxide and water into oxygen and sugar.

WHAT IS BIOFUEL?

Biofuels are futuristic fuels that can power cars and trucks with crops, algae and even rubbish. Here's how they're produced

WORDS **MIKE JENNINGS**

Wheat and maize are used to make bread, pizza and other delicious foods, but in a few years they could also power your car. Renewable biofuels could soon replace the harmful fossil fuels that we're used to using. It's now well-established that fossil fuels are incredibly harmful to our health and the environment, and they're not renewable, either. When so many people rely on petrol and diesel to power vehicles, it makes sense to develop a renewable alternative that's easy to use.

That's where biofuel comes in. The most common biofuel produced globally is ethanol, and it's used frequently in Brazil and the US, while biodiesel is more popular in Europe. Ethanol is a clear, flavourless alcohol that's created by fermenting and distilling sugary crops like wheat, corn and sugar cane. It's combined with petrol to make fuel more environmentally friendly, and it's already in widespread use. More than 95 per cent of petrol sold in the US contains ethanol, and E10 fuel – made from ten per cent ethanol – is now the standard petrol in the UK. Alcohol combines with oil or fat to create biodiesel. It works directly in many car engines, but it's usually combined with conventional diesel to create a more effective blend. It's produced from vegetable oil, animal fat, soy or palm oil.

There's a huge amount of potential in biofuel, and most of the big energy companies have already invested – but emerging energy sources like ethanol are first-generation biofuels, and they've got issues that need fixing before they can go mainstream. It currently takes more ethanol than gasoline to produce the same amount of energy, for instance. Production is expensive, and several parts of the process sometimes use fossil fuels, which means that some biofuels aren't actually carbon neutral.

Did you know?
Brazil and the US produce 87 per cent of the world's ethanol

Some environmental campaigners also say that it would be more useful to grow crops for food rather than biofuel, and that growing crops for biofuel can cause problems with soil erosion and deforestation. Using land for fuel rather than food can lead to an increase in food prices, too, and can hinder natural habitats. Crop and fat-based biofuels may not be perfect, but those aren't the only biofuels available – some organisations are creating biofuels with algae instead. This process uses water and land that often isn't suitable for many other situations, so it doesn't take up space that's useful for food production, and it often has better yields than other types of biofuel components.

There's plenty of development beyond algae, too. Many companies are developing crops specially for biofuels, and those will improve yields, increase efficiency and reduce costs.

THE ALGAE ALTERNATIVE

Algae is touted as a more efficient option for biofuel creation – but how does this work?

1 SPECIALIST FACILITIES
Algae for fuel production is usually grown in a nutrient-rich water system called a bioreactor that's exposed to sunlight.

4 WATER MESS
Once algae is harvested, it's usually dehydrated. After that, oil and carbohydrates can be used to create biodiesel or ethanol.

5 SURFACE PRESSURE
Alternative methods involve subjecting algae to high-pressure and temperature environments to extract oil to use in biofuels.

SWEET REACTIONS

Creating ethanol is a complex chemical process. Plant cells contain cellulose, hemicellulose and lignin. Acids, enzymes and other chemicals break the plants down, and the result is a pure sugar solution called sucrose. At this point, scientists add yeast, and the solution heats to between 250 and 300 degrees Celsius. The yeast has an enzyme called invertase. Heat activates this, converting the sucrose into glucose and fructose. These sugars combine with another enzyme, called zymase, which converts them into ethanol. That ethanol still has lots of water, though, so the next step involves boiling. Because ethanol boils at 78.3 and water boils at 100 degrees Celsius, the ethanol boils and turns into vapour first; it can be separated from the water, condensed back to liquid form and used for biofuel.

Biofuel can increase the lifetime of your car's engine

Some buses now run entirely on biofuel, and more planes are using it too

Some even use seaweed. Scientists are also working on schemes that will be able to extract biofuels from household waste, wood chips and other junk – a move that could massively increase the material that's viable for biofuel production. These second-generation biofuels could make biofuel far cheaper and more accessible, and help cut emissions down.

> "Wheat and maize could power your car in a few years"

Top-tier motorsport competitions are now using biofuel to improve emissions and sustainability

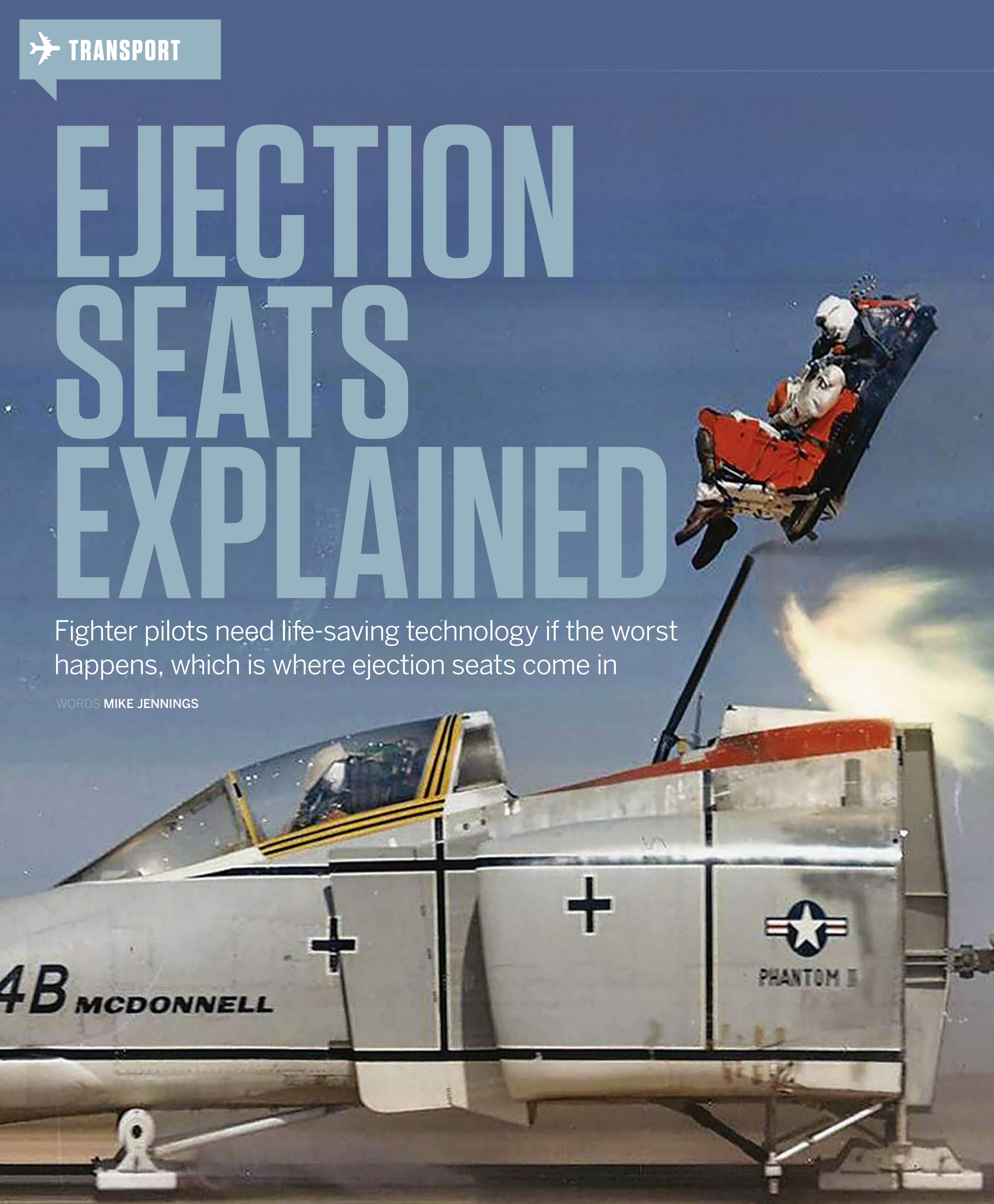
RACING AHEAD

The World Rally Championship (WRC) is a global motorsport competition that made a groundbreaking switch to biofuel for its 2022 season. The WRC now uses a second-generation biofuel made from organic waste material, which is combined with synthetic fuel. The production process uses renewable energy and takes carbon dioxide out of the atmosphere thanks to carbon capture. It's the first time that a fossil-free fuel has powered a world motorsport championship. This isn't the only time you'll see biofuel used in a high-performance situation, either. Formula 1 now runs with a ten per cent biofuel blend, and the aviation and shipping industries are increasing their usage. It's even being used by space start-ups.

EJECTION SEATS EXPLAINED

Fighter pilots need life-saving technology if the worst happens, which is where ejection seats come in

WORDS **MIKE JENNINGS**



We're all used to seeing planes, but behind that familiarity you'll find an awful lot of groundbreaking technology and some of the world's most advanced safety gear. If you see a military jet soaring overhead, it'll have ejection seats that can save the crew's lives in emergencies. Ejection seats work as the name suggests: they eject pilots from planes if anything goes seriously wrong. They're fast and often brutal mechanisms that never consider comfort, but speed is more important if your plane's about to crash.

Most of the time, ejection seats work by propelling pilots from the cockpit using rocket-powered motors or explosive charges. This system allows seats to accelerate extremely quickly, which gets people out of danger. Once they're clear, the pilot can use a parachute to safely navigate their way to solid ground.

Ejection seats are almost always found on military planes – the sorts of jets that can potentially come under fire from enemies. Many planes have more than one seat, and larger planes eject crew members at different angles to avoid mid-air collisions. They're not used on commercial planes – which have more comfortable evacuation systems – though they've occasionally been fitted to helicopters, and some spacecraft also include ejection seats.

These seats are among the most complex bits of kit on any aircraft, but ejection seats work using some simple principles. Pilots grab a handle to trigger an electronic mechanism that releases the cockpit's roof. Systems on the seat measure the plane's speed and aerodynamic pressure and a computer calculates which ejection mode is suitable – different speeds and altitudes require different ejection processes.

A rocket or motor system propels the pilot's seat up guide rails to make sure the seat gets free of the plane safely, and the seat detaches from the plane's vital systems as it accelerates away from the aircraft at frightening speeds – the entire process takes less than two seconds. A small parachute called a drogue unfolds before the main parachute – it slows and stabilises the seat immediately after ejection. Once the pilot is clear of the plane, they're released from the seat. They can then deploy their main parachute and navigate slowly to the ground below. That sounds simple, but there's plenty else going on. Ejection seats usually have oxygen bottles that deploy when the seat is released because pilots often fly so high that the air outside is too thin to breathe normally.

Ejection seats include radio and GPS beacons so the pilot's military can track them down once they've left the plane. The seats also include some vital kit to help pilots survive in any situation. They usually have life rafts and vests that automatically inflate if the pilot has to land at sea, flares for visual identification and sleeping bags, ponchos, hats and gloves for cold environments. These seats often use more comprehensive survival options too, from water and filtration systems to woodland camouflage. It's not uncommon to find mirrors, whistles, candles, insect repellent and even sunscreen in them.

Did you know?

Over 7,000 lives have been saved by ejection seats

Major seat manufacturers give pilots a tie, patch and certificate to commemorate a successful ejection

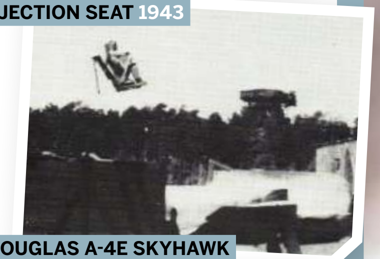
WORKING TOWARDS A SAFE LANDING

Ejection seats might be a fixture in modern fighter jets, but they've been around for a long time. Engineers were experimenting with similar systems as early as 1910, and the first modern ejection seats, like the Floyd Smith Aerial Life Pack, were being used by the early 1920s. World War II saw a huge increase in airborne warfare, thus ejection seat designs improved drastically, with German companies leading the way. The first seats used compressed air to remove pilots from cockpits. Other models required gunpowder, and some used the kinds of cartridges that you'd usually see in shotguns. By this point, though, many planes still didn't have ejection seats, so pilots still had to climb free themselves. After World War II, planes got faster, and the need for ejection seats was more pressing. Development continued quickly, with rocket-propelled seats arriving in 1958, and designs have been improving ever since.

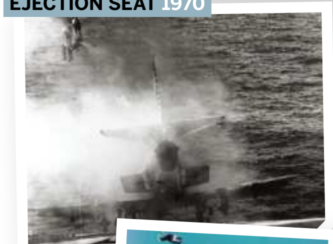
FLOYD SMITH AERIAL LIFE PACK 1918


In Action
NEVER FAILE
FLOYD SMITH AERIAL EQUIPMENT CO.

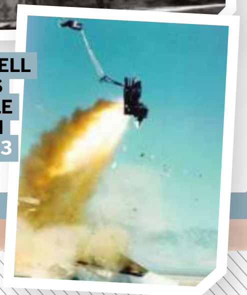
FOCKE-WULF FW 190 EJECTION SEAT 1943



DOUGLAS A-4E SKYHAWK EJECTION SEAT 1970



MCDONNELL DOUGLAS F-15 EAGLE EJECTION SEAT 2003



LAST RESORT

If a pilot is at the point where they're using the ejection seat, it's their last viable course of action – it means that their plane is doomed and they've got no other options. Pilots usually fight until the last possible second to save their plane and themselves, but abandoning an aircraft can be expensive. The Royal Air Force's F-35 Lightning jets cost nearly £90 million ($118 million) each. There are only a few situations where an ejection is necessary. If a jet has been irreparably damaged due to enemy fire then a pilot will have to make a quick getaway, and a pilot may have to eject if the plane has encountered a technical issue in the field or during testing. Different situations need different ejection technology, too, so sensors on the seat determine which mode the plane uses when it flings the pilot into the sky.

MODE ONE

SPEED: **Less than 288 miles per hour**
ALTITUDE: **Less than 4,575 metres**

A low-speed, low-altitude ejection is a simpler affair that doesn't need the small drogue parachute.

MODE TWO

SPEED: **Beyond 288 miles per hour**
ALTITUDE: **Less than 4,575 metres**

This high-speed mode deploys the drogue and protective seat restraints to protect fast-moving pilots at low altitudes.

MODE THREE

SPEED: **Any speed**
ALTITUDE: **Beyond 4,575 metres**

At high altitudes, the drogue and seat restraints are required alongside an automatic parachute, survival kit and life raft deployment.

VITAL COMPONENTS

Ejection seats are complex. We explore the key technology in these life-saving devices

DROGUE
The drogue is a small parachute that stabilises the seat before the main parachute is required.

KITTED OUT
The pilot's survival kit can include cold-weather gear, life rafts, flares, water and camouflage, depending on the environment.

PARACHUTE
A parachute automatically deploys to help pilots safely navigate to dry land or the sanctuary of the sea.

BACK TO BASICS
Sturdy back supports keep pilots safe during the violent ejection procedure, but despite that, spinal injuries can happen.

ACTIVATION
The seat is activated using side-mounted handles, levers between the pilot's knees or when pilots apply a protective face covering.

ROCKETS AND RAILS
Rockets beneath the seat propel the pilot free from the plane very quickly, and rails guide the seat to freedom.

LEG PROTECTION
Leg restraints prevent injuries when pilots are ejected from planes at extreme speeds.

> "Ejection seats are fast and brutal, but speed is more important"

Did you know?
Over 70,000 ejection seats have been supplied for aircraft

HOW THEY WORK

It's a split-second process, but what actually happens when a pilot makes an emergency exit?

1 OPEN UP
Pilots pull a lever between their knees or to the side of the chair to release the plane's canopy.

2 ROCKET POWER
Once the roof is free, rockets fire to propel the seat along guide rails. The pilot receives emergency oxygen.

3 GETTING HEIGHT
Ejection seats shoot pilots at least 30 metres into the air, and sometimes as far as 100 metres.

4 FAREWELL
Once the pilot is free from the plane, the ejection seat falls away – it's done its job.

5 SLOW DESCENT
A parachute releases automatically, sometimes only when the pilot has descended to a certain altitude.

6 LANDING STRIP
Pilots use the parachute to navigate to a safe landing, whether it's on land or sea, thanks to an built-in life raft.


Some older seats subjected pilots to 20g of force; humans can't withstand much more


A modern ejection seat can cost between $140,000 and $400,000 (£182,900 and £522,580) depending on its configuration

EJECTION FORCES

Ejection seats are serious business, with pilots describing an ejection as one of the most violent forces they've ever experienced. And when you consider the physics at play, that's no surprise. Ejection seats propel pilots for between 30 and 100 metres at speeds beyond 250 miles per hour in a process that takes half a second – and when the planes are flying at speeds upwards of 750 miles per hour. These extreme speeds put huge pressure on the human body. Pilots typically experience up to 14G of force when they eject, which means that an 80-kilogram person will experience 1,632 kilograms of pressure on their body. Unsurprisingly, this can cause injuries – it's not unheard of for pilots to break limbs because they're thrown around so violently thanks to ejection seat g-forces.

Ejection seats use explosives and extreme force, so warnings are needed

Races take place globally using specially designed craft that have been modified for racing

THE JET SET

Personal watercraft work thanks to smart technology and basic physics

JET SKI TECH

Jet skis are popular around the world, but how do these tiny boats go so fast?

WORDS **MIKE JENNINGS**

If you've ever been on a beach holiday, you'll have seen jet skis zooming around on the water. These lightning-quick boats look effortless and exciting, but plenty of hard work beneath the surface helps these pocket rockets bounce across the waves. You'd be forgiven for thinking that a jet ski operates with motors and propellers, but that's not the case – they work with powerful jets of water. And despite those jets, they're not actually called jet skis: that's a brand name that's become popular, just like how hoover is now a common term for vacuum cleaner. If you want to be accurate, call them personal watercraft.

Jet skis work thanks to a sleek system that relies on water and physics. A petrol engine powers an impeller which rotates inside a tube, and this sucks water into the ski and powers it out of a rear-facing nozzle at a higher speed. That speed increase gives the ski its forward momentum. The nozzle turns to allow riders to steer the ski, but the craft don't have any brakes.

The sheer popularity of personal watercraft means they're not just great tourist rental options. Personal watercraft races take place globally – the current world championship launched in 1996 – and jet skis are often used by lifeguards, police departments and navies. It's no surprise that they're used so widely: they're small, fast and manoeuvrable, and they're cheaper, safer and easier to use than many conventional boats. Today, personal watercraft are found in sit-down and stand-up designs, with the former more popular and the latter often only used by racers and stunt riders. Expect to shell out plenty of cash for one, too – a new jet ski costs at least £10,000 ($12,000).

> "These lightning-quick boats look effortless and exciting"

Futuristic jet skis will balance greener, eco-friendly designs with more luxury

JETTING TO THE FUTURE

Most personal watercraft still rely on petrol motors, so it's no surprise that tomorrow's jet skis will take a more environmentally conscious approach. Just like the motoring industry, the next wave of personal watercraft will use electric motors instead. Electric personal watercraft should still deliver loads of performance in a more eco-friendly package. Taiga's Orca hits 65 miles per hour thanks to a 180 brake horsepower electric drive system, and the reliance on electric hardware means you get instant torque and incredible acceleration, just like in electric cars. Because electronics and water don't mix, expect battery-powered personal watercraft to use robust, fully waterproof systems. Futuristic personal watercraft will also become more luxurious. Right now you'll find high-end models with Bluetooth connectivity, GPS systems and speakers, and next-generation devices will have 4K screens, better audio kits and reversing cameras. Some will even have Wi-Fi, sonar units, companion smartphone apps and their own operating systems.

DID YOU KNOW? Kawasaki sold more than 200,000 of its JS400 in 1973, starting a huge new trend for these versatile craft

HANDLING THINGS
Drivers change the nozzle's direction to steer the ski. They're more manoeuvrable at higher speeds and with a stronger jet.

Did you know?
Top-end personal watercraft have four-stroke engines

TUBULAR
A tube at the bottom of the ski contains an impeller – an underwater version of a plane propeller.

BLOCKED OUT
The engine rotates the impeller, which sucks water into the ski, while a grate stops debris from entering the vehicle.

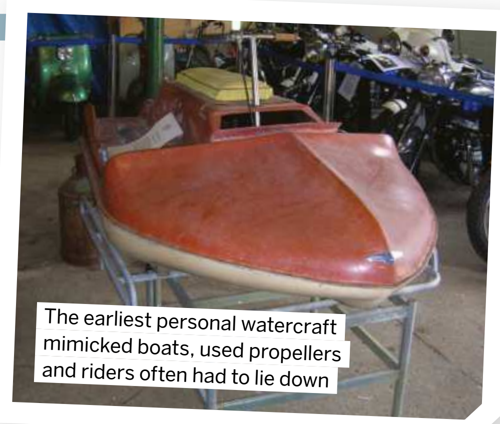
NO BRAKES
Riders can switch the drive shaft and impeller's direction, allowing the ski to reverse, but personal watercraft don't have brakes.

WATER POWER
The impeller's trio of blades suck water in, speed it up and propel it towards the pump at the rear.

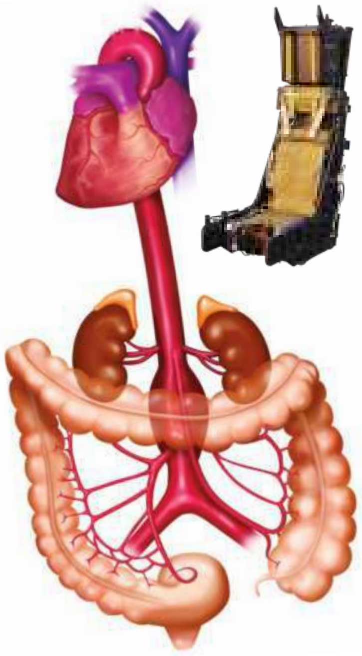
NARROW OPENING
The rear nozzle is narrow, which increases pressure and speed – it's this speed increase that propels the ski forwards.

PERSONAL WATERCRAFT OF THE PAST

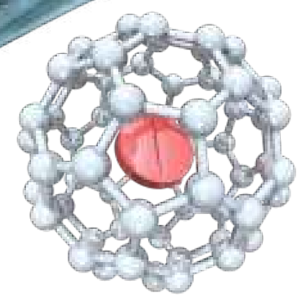
The term jet ski may have been launched by Kawasaki in 1972, but the first personal watercraft were called 'water scooters' and appeared in Europe in the 1950s. They used small outboard motors, and riders often needed to lay down to pilot these craft. By the 1960s, a Norwegian-American designer called Clayton Jacobson II invented the more familiar internal pump system, and Bombardier produced his designs – today the company still sells its Sea-Doo brand. Kawasaki's stand-up, single-rider jet skis arrived in the US in 1973, and sit-down models soon became more popular. Today pioneers like Kawasaki and Bombardier sell personal watercraft alongside Honda and Yamaha.



The earliest personal watercraft mimicked boats, used propellers and riders often had to lie down



HOW IT WORKS Annual



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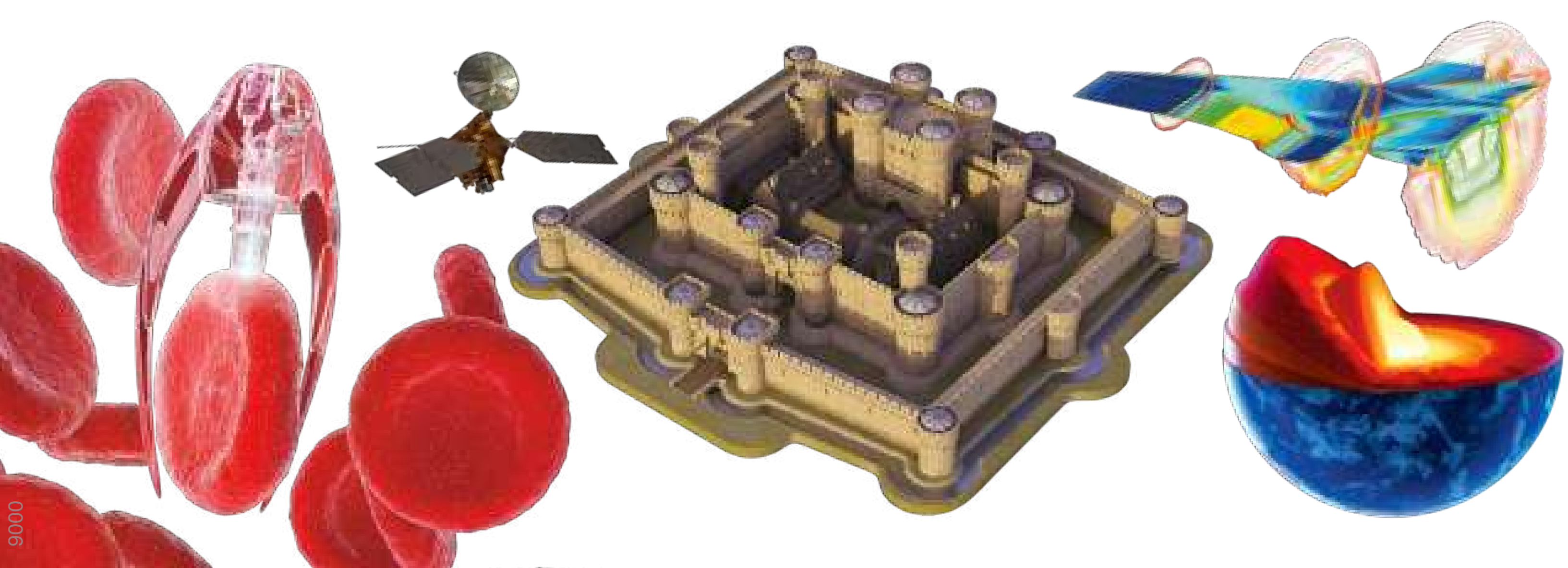

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